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CPO AMBIENT NOISE STUDY

CPO SPECIAL REPORT NO. 1

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Nuclear Test Detection Office

27 June 1967

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTD)

SECTION I

INTRODUCTION

A thorough and comprehensive analysis of the ambient seismic noise field existing at the Cumberland Plateau Observatory (CPO) located E-SE of McMinnville, Tennessee, has been the partial goal of Contract AF 33(657)-14648. Included in this investigation has been the analysis of:

- Absolute noise power density spectra
- Spatially organized low velocity noise
- Spatially organized high velocity noise

The purpose of this special report is to summarize the results of this analysis and present in detail the data used to derive the presented conclusions. The data for this analysis covers the period January to March 1963* and 1 May 1965 through 31 October 1966.

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*Texas Instruments Incorporated, 1963: Synthesis and Evaluation of Six Multichannel Filter Systems Based on Measured Correlation Statistics of Ambient Noise at Cumberland Plateau Observatory Designed to Operate on Rings of Seismometers, AF 33(657)-12331, 31 Dec., p. III-1.

SECTION II

SUMMARY AND CONCLUSIONS

Results of this study have shown that the ambient noise field at CPO has not changed significantly over extended time periods, nor has it changed on a daily or seasonal basis. However, there is a change in the noise field which can be related to microseisms generated along the Atlantic and Gulf Coast regions and, possibly, the Great Lakes region.

These results imply that an accurate modeling of the CPO noise field can be used to generate a multichannel filter set which can be used in a digital MCF processor to reject ambient noise throughout the year, except for periods of intense microseismic activity.

The remainder of this section presents a summary of each of the different areas investigated.

A. SINGLE-CHANNEL AMBIENT NOISE POWER DENSITY SPECTRA

Single-channel power density spectra were computed on a daily basis during the period 1 May 1965 through 31 October 1965 and on a weekly basis from 1 November 1965 through 31 October 1966. These spectra were computed from 8.33 min of noise recorded at the center seismometer of the array during various hours of the day. The 1.0 cps ambient noise energy for this period averaged approximately 1.0 $m\mu^2$ of the ground motion/cps with variations as large as ±7 db. Variations in the power density spectra were studied over various time periods and hypotheses for the source of the variations were formulated.

To study the periodic variations in the noise field, power density spectra were computed hourly over a 48-hr period. These spectra did not exhibit any large periodic changes in shape. However, in this study some minor variations in power were observed at several defined frequencies or frequency bands and are probably attributable to cultural activity near the station. The largest variation in power, occuring at [illegible].4 cps, could not be restricted to any consistent time period and appears to be randomly generated by a cultural or natural source to the northwest of the array. Only at 1.5 cps could a slight, regular increase in the noise level be correlated with increased cultural activity.

Studies for longer periods of time exhibited noticeable variations at frequencies below 1.5 cps. These have been correlated with the development of low pressure areas off the Atlantic and Gulf of Mexico coastlines. A direct correlation was noted between the intensity of the low pressure areas and the increase in power at the lower frequencies.* Fluctuations in the power level were also noted in the frequency band 2.25 to 2.75 cps and were probably due to local cultural activity and weather conditions.

B. 3-DIMENSIONAL NOISE POWER DENSITY SPECTRA

Analysis of the 3-dimensional noise power spectra for CPO shows that several spatially organized noise sources exist in the frequency range 0.25 to 2.25 cps. These results also show that the spatially organized noise field has remained time-stationary over the extended time period of 1963 through 1965 except for changes which occur during periods of low pressure and when tropical storms exist at sea.

At frequencies below 1.0 cps, the main contributor to the organized noise field is high-velocity mantle P-wave energy and noise generated in the area of the Atlantic Coast, Gulf of Mexico and possibly the Great Lakes region. Narrowband filtered playbacks of the ambient noise indicate that the long-period energy traveling from the direction of the coastline propagates across the array with an apparent horizontal velocity of approximately 3.2 km/sec. This velocity closely agrees with the previously developed dispersion curves for Rayleigh wave energy at CPO.** The results also show that the contribution from the direction of the coastline becomes significantly large with the development of low pressure areas at sea. This increase in power can be detected at frequencies as high as 1.75 cps.

The 3-dimensional power-density spectra also show the existence of several coherent noise sources in various directions around CPO in the frequency range 1.25 to 2.25 cps which propagate across the array with an apparent horizontal velocity of approximately 3 km/sec. The predominate noise contribution comes from a N-NW direction, an area of numerous streams and dams, but a definite generating source cannot

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* Appendix A gives a brief review of studies relating to storm- and ocean-generated microseism.

** Texas Instruments Incorporated, 1965: CPO Quarterly Report No. 2, AF 33(657)-14648, 15 Nov.

be assigned to any of the coherent noise due to the lack of information concerning possible generating sources in the various directions around CPO. The various coherent noise sources seem to remain time-stationary except for slight power fluctuations.

Prediction filtering results have indicated that the percentage of spatially coherent noise changes significantly with the occurrence of tropical storms and low pressure areas off the coastline, indicating an increase in the spatially organized noise for all frequencies below 1.75 cps. This increase is comparable to an equivalent power increase in the single-channel power-density spectra during the same time period.

C. HIGH-VELOCITY 3-DIMENSIONAL NOISE POWER DENSITY SPECTRA

This section was directed toward investigating ambient noise properties in the signal velocity regions of wavenumber space. A strong coherent noise lobe in the signal velocity region will decrease the S/N ratio for signals from that direction. Therefore a study of this region was conducted using high resolution wavenumber spectra techniques.

In the velocity region of interest (velocities greater than or equal to 8.1 km/sec), the mantle P-wave energy is a strong contributor of power to the spatially coherent ambient noise field in the frequency band of 0.25 cps to 1.5 cps. Directional power distribution curves of the CPO noise energy were calculated for various directions and velocities of the signal region. In each case, the distributions approached the estimated mantle P-wave noise level.

The 1.0 cps energy is particularly interesting since it was found to be highly directional. Predominant 1.0 cps energy could be detected from the south or Gulf Coast area for all velocities studied. Also, significant 1.0 cps energy from S60°W exists with a velocity greater than or equal to 12.6 km/sec.

At 1.25 cps, the most significant noise energy appears to arrive from the direction of the Great Lakes region with velocities of approximately 8.1 km/sec. Directional properties for the P-wave contribution at other frequencies appear to be random for the higher velocities.

D. IMPLICATIONS ON MCF ON-LINE PROCESSING

Results of this noise study indicate that on-line multichannel processing can be effectively conducted at CPO. Furthermore, they indicate that a multichannel filter (MCF) designed from ensemble or average noise can be effectively used over extended periods of time. However, during periods of low pressure or storms at sea, greater efficiency may be acquired by using a filter designed from corresponding data.

The high-resolution power spectra over the high velocity noise regions presented results which exhibit a possible interference with certain incoming signals. This noise energy propagates from the south or Gulf Coast region and, therefore, during the mentioned disturbances at sea, could reduce signals from this direction with the same apparent P-wave velocity. This result is discussed in the signal-to-noise study presented in the CPO Annual Report No. 1.* However, it is important to note that the low and high-velocity noise propagate from the same direction and probably can be attributed to the same source.

*Texas Instruments Incorporated, 1966: Cumberland Plateau Seismological Observatory, Annual Report No. 1, AF 33(657)-14648, 15 Sept.

SECTION III

SINGLE-CHANNEL POWER SPECTRA

The ambient noise data has been recorded continuously from 1 May 1965 through 31 October 1966 under this contract. Recorded data was sampled and studied at various intervals so that the noise field could be effectively analyzed over an extended period of time. The ambient noise level of the recorded data was observed to vary significantly during various time periods. These variations can be evaluated through computing and studying single-channel absolute power density spectra.

This section presents a detailed analysis of the single-channel power density spectra. The first three quarterly reports published under this contract contain various examples of single-channel power density spectra which relate to this section.

A. AMBIENT NOISE RECORDINGS

1. Acquisition of Data

The 10-channel data for CPO was shipped to Dallas where a 12-min sample of noise data was selected for each day during the period of 1 May 1965 through 31 October 1966. Also, an equivalent noise sample was selected on an hourly basis for a 48-hr period on 2 October and 3 October 1965. These noise samples and corresponding calibration data were then digitized at the Dallas facilities, and paper playbacks of the records were produced for preliminary analysis of the noise.

2. Ambient Noise Levels

Visual analysis of the playbacks revealed striking changes in the noise level during various time periods. An average, or normal, ambient noise level is shown in Figure III-1 while an extremely quiet ambient noise period, 6 August 1965, is shown in Figure III-2. Several periods of very high ambient noise level were recorded. These corresponded to periods when low pressure areas were present in the Atlantic Ocean and/or Gulf of Mexico. A representative recording of the high noise level is presented in Figure III-3. These variations will be analyzed in greater detail in the section on power density spectra.

B. COMPUTATIONS OF POWER SPECTRA

Single-channel power density spectra were computed daily from 5-min ambient noise samples recorded during the period 1 May 1965 through 31 October 1965 and weekly from 1 November 1965 through 31 October 1966. Power density spectra also were computed hourly from data recorded

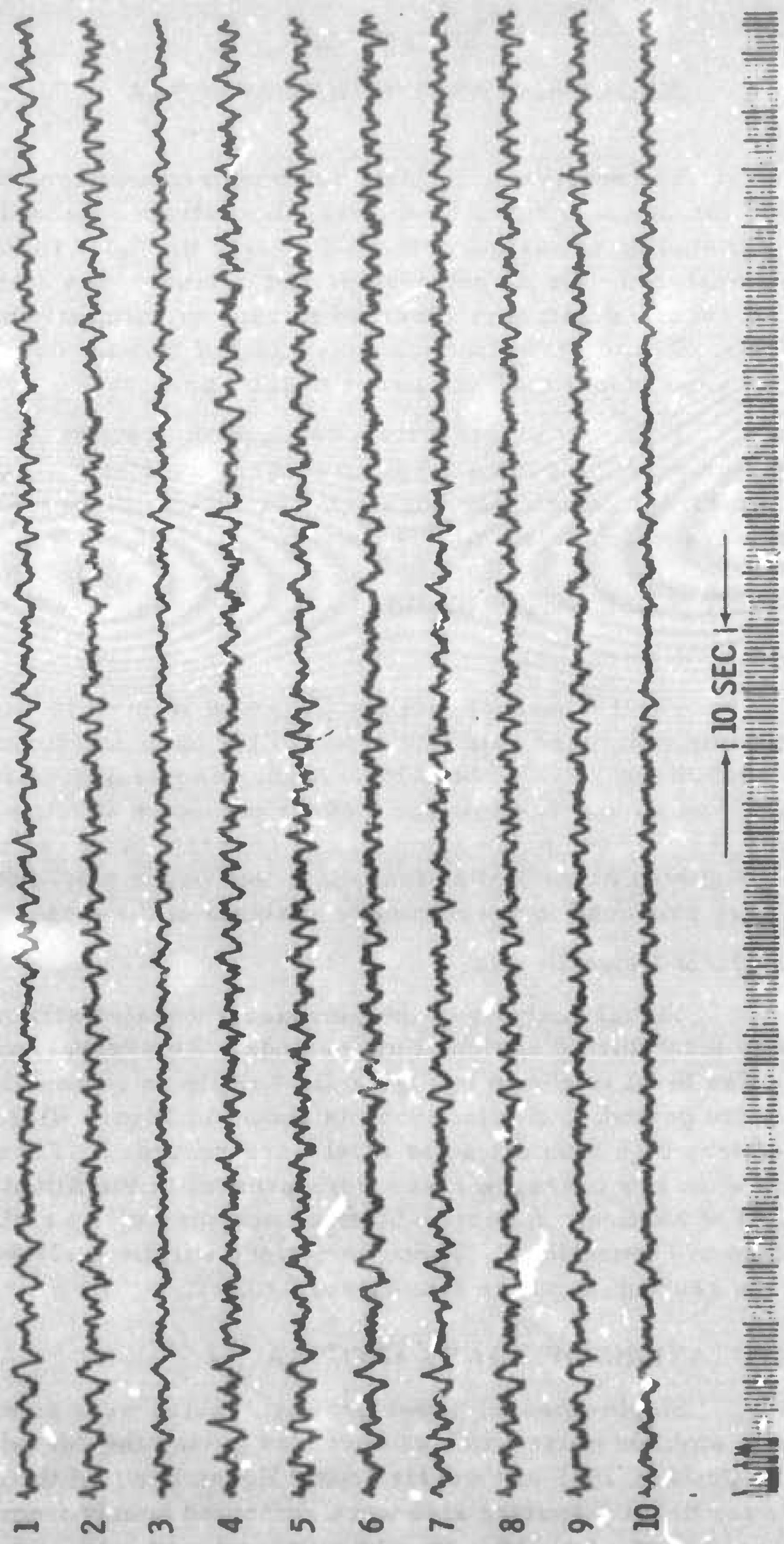

Figure III-1. Average Ambient Noise Recording, 24 September 1965

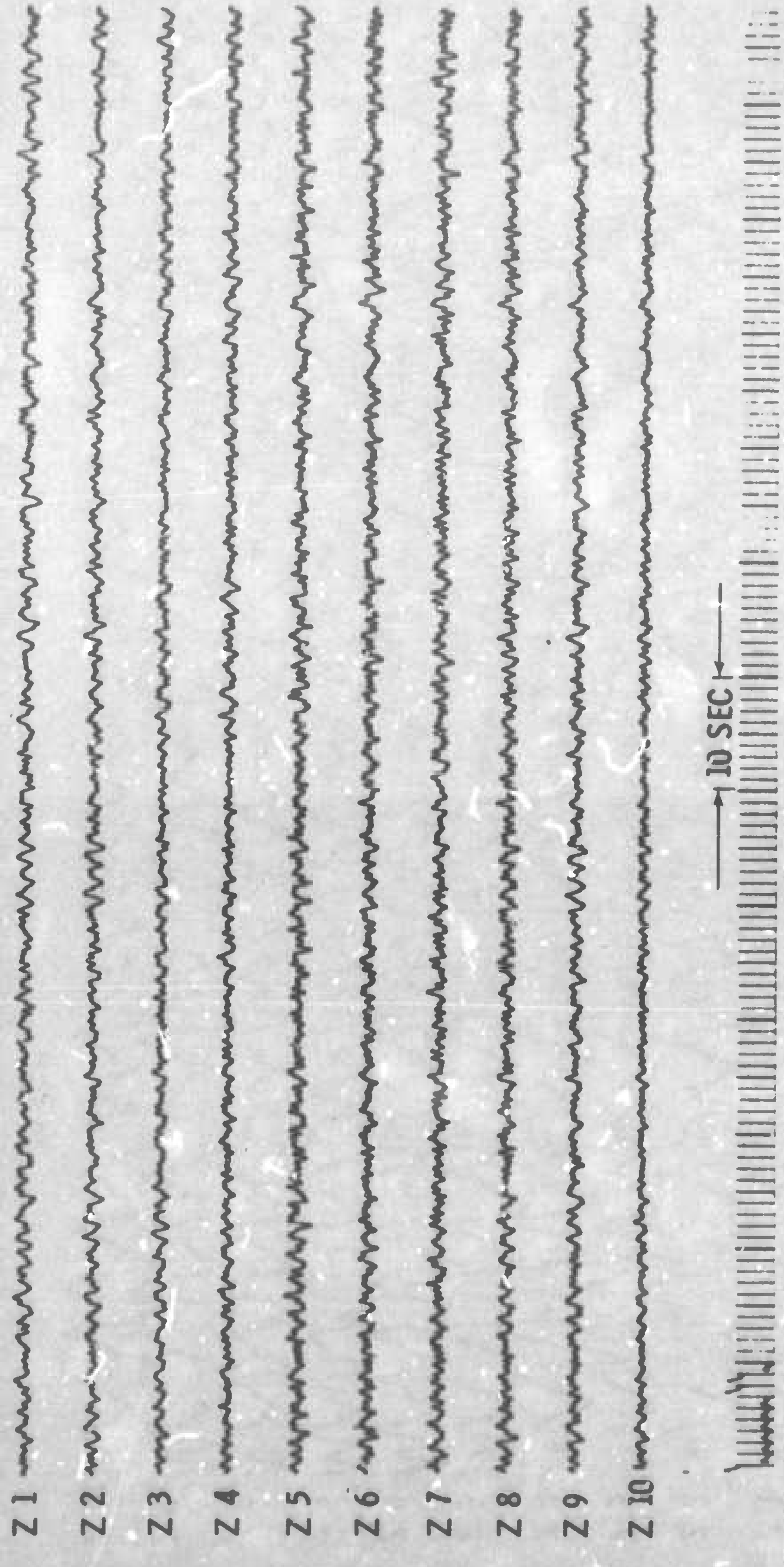

Figure III-2. Low-Level Ambient Noise Recording, 6 August 1965

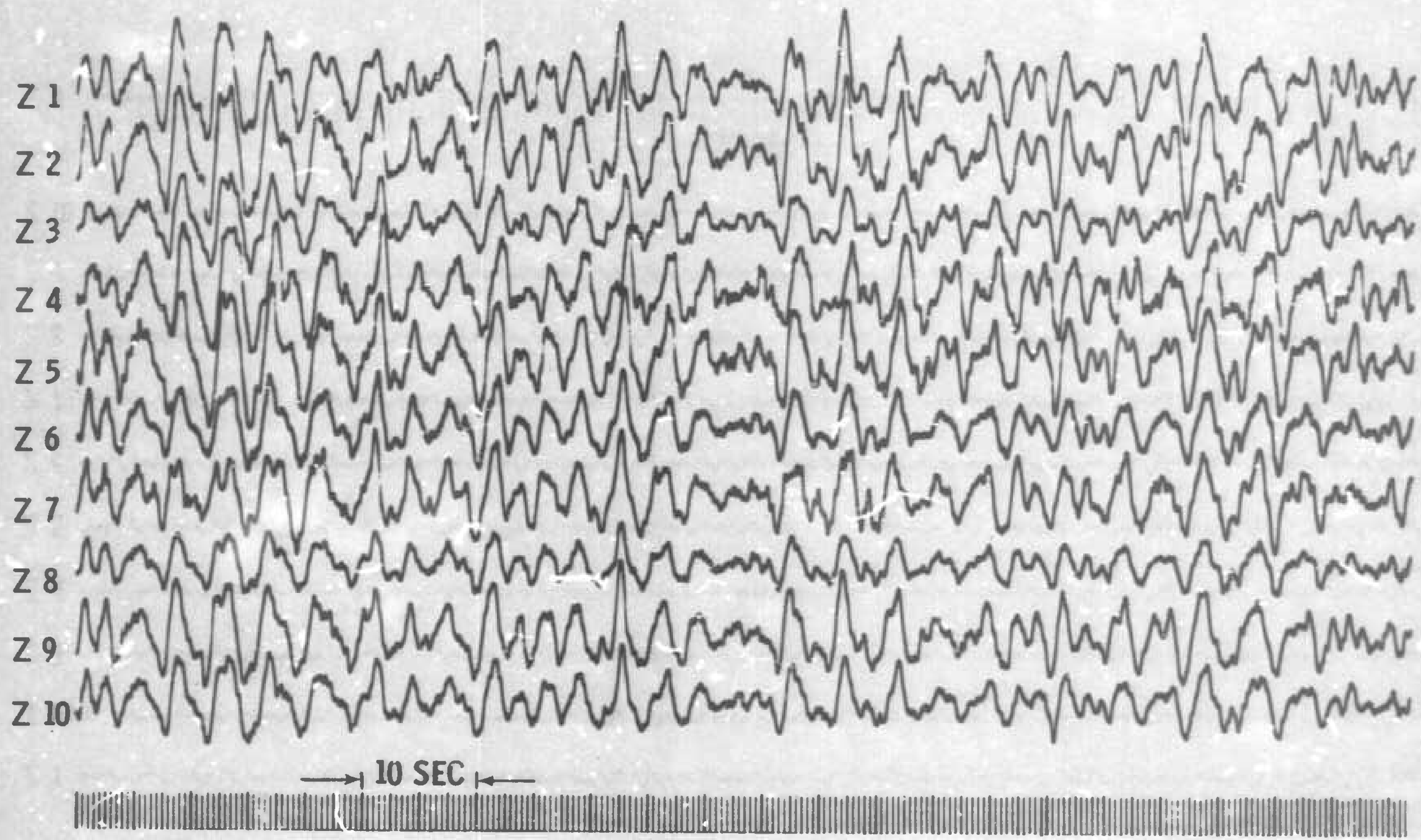

Figure III-3. High-Level Ambient Noise Recording Due to Low Pressure Area in Atlantic Ocean, 6 September 1965

during a continuous 48-hr period on 2 October and 3 October 1965.

C. POWER DENSITY SPECTRA VARIATIONS

The power variation of the ambient noise over various time periods was considered in great detail. Efforts were made to determine the existence of periodic power fluctuations that could be restricted to a particular time of day or to certain days or seasons of the year. The results of the study are presented below.

1. Hourly Variations

a. General Variation

Every power spectra computed was analyzed with respect to the time of day the noise was recorded. The 48-hr of continuously recorded data previously mentioned serves as the best means of determining any hourly variations.

The six representative power spectra from the 48-hr period, shown in Figure III-4, do not indicate any large periodic changes in the spectra. However, slight changes in the power spectra shape are observed from one noise sample to another but cannot be considered as a function of the time of day. Such changes are probably due to local weather conditions or some other time-independent noise generator near the array. The power at various frequencies was measured from the spectra as a function of the time of day and is presented in Figures III-5 through III-7. A periodic daily fluctuation is not evident at any of the selected frequencies except, possibly, 1.5 cps. At this frequency, a slight increase in power occurs daily between 8 a.m. and 6 p.m. which correlates to a period of increased local cultural activity.

b. Microseismic Variation

It is interesting to note that the significant increase in power of the 3-sec period microseismic energy shown in Figure III-6 occurs simultaneously with the passage of a cold front across the Atlantic and Gulf of Mexico coastlines. The passage of the cold front may also account for the slightly higher noise level of 2 October 1965. This increase in energy is discussed further in Section III-C2.

c. Spectral Peak Variations

Large variations in the power density spectra have been noted for the well-defined frequencies of 1.4, 1.9 and 2.8 cps and appear as sharp peaks in the spectra. Efforts to relate these variations to time of day were unsuccessful as is shown in Figure III-7. Other efforts to relate these peak fluctuations to the time of month and year also were unsuccessful

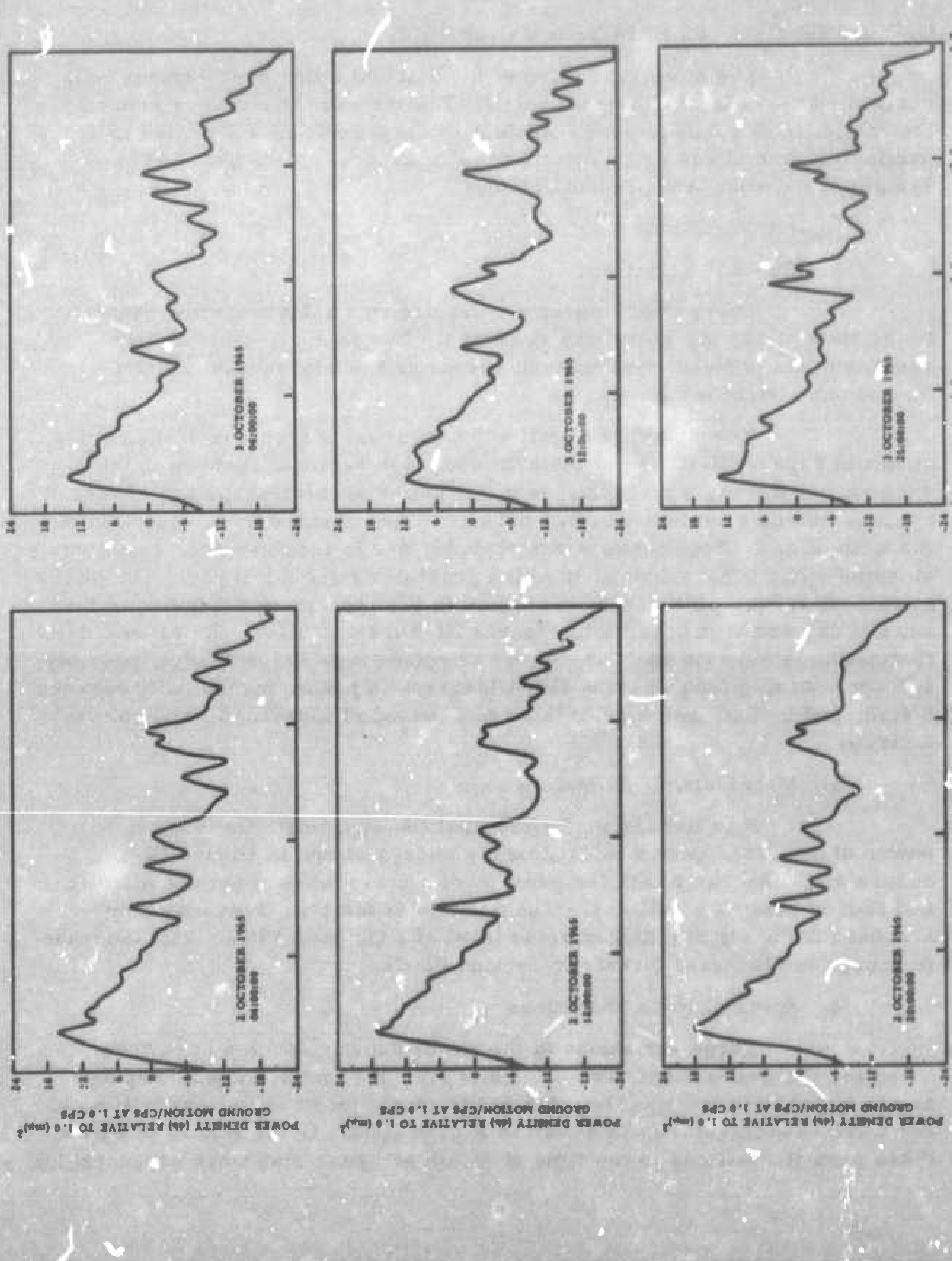

Figure III-4. CPO Ambient Noise Power Density Spectra for 2 October 1965 and 3 October 1965

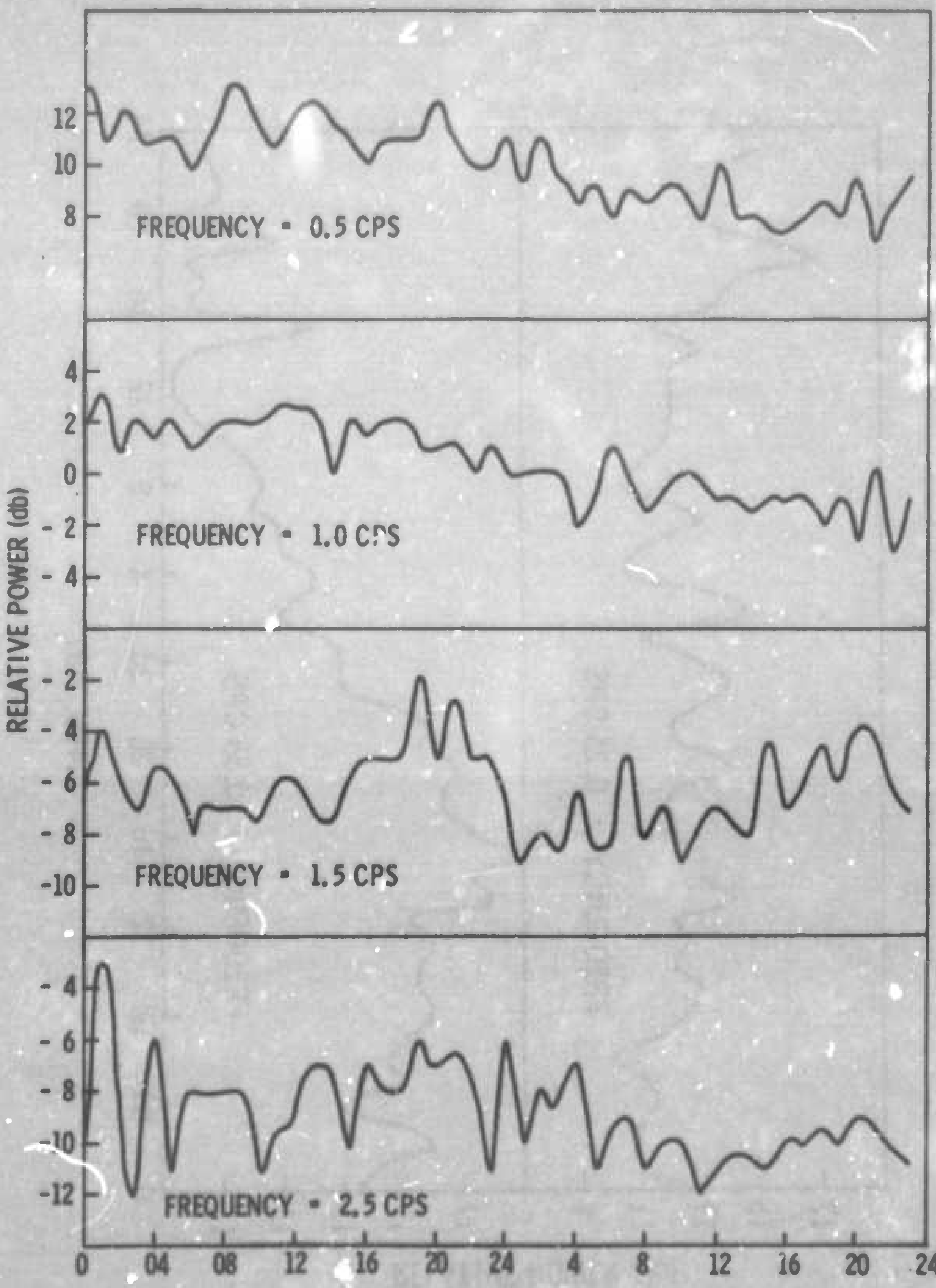

Figure III-5. CPO Noise Power Variations Over a 48-Hr Period

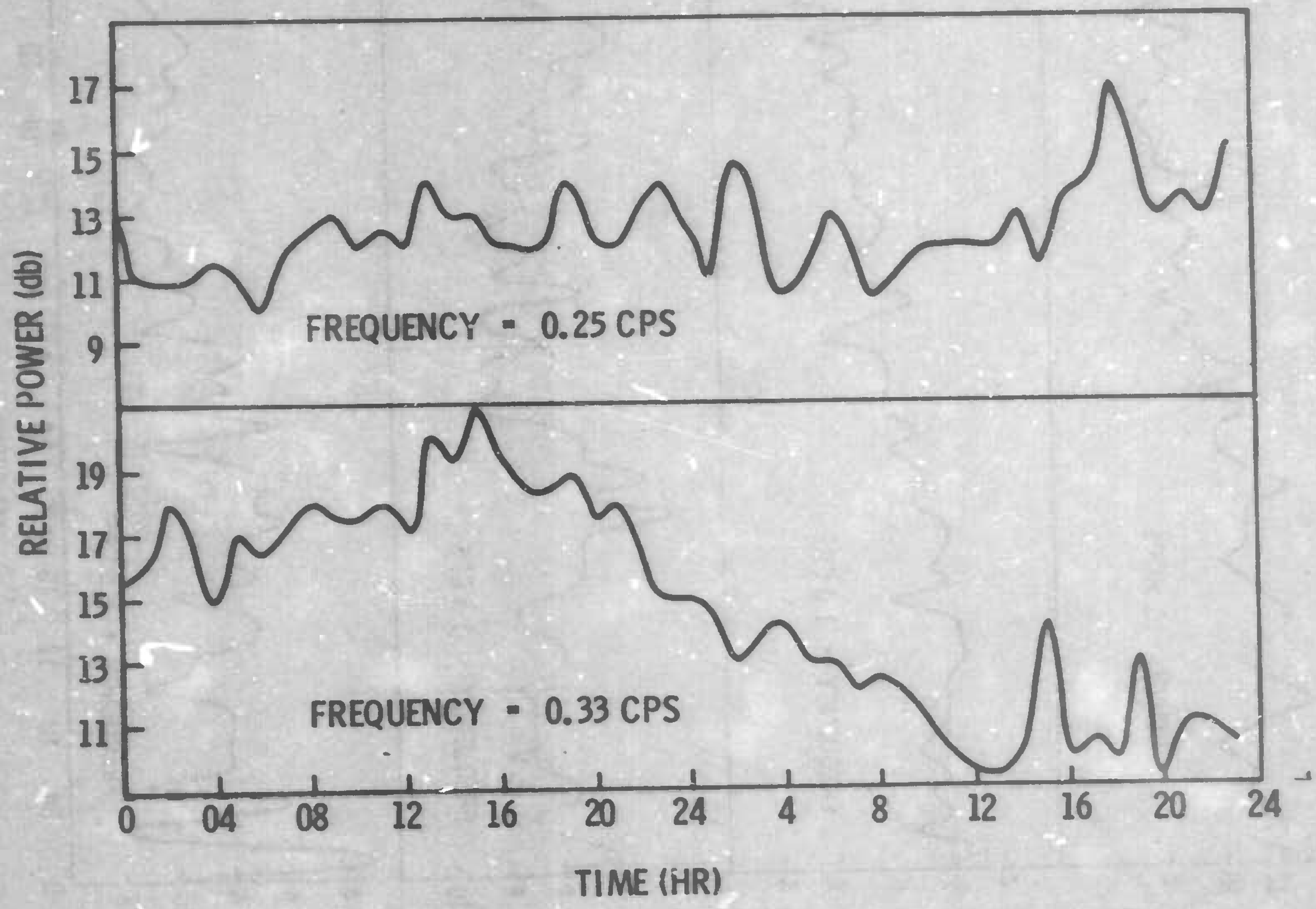

Figure III-6. CPO Noise Power Variations of 4- and 3-Sec Period Microseisms Over a 48-Hr Period

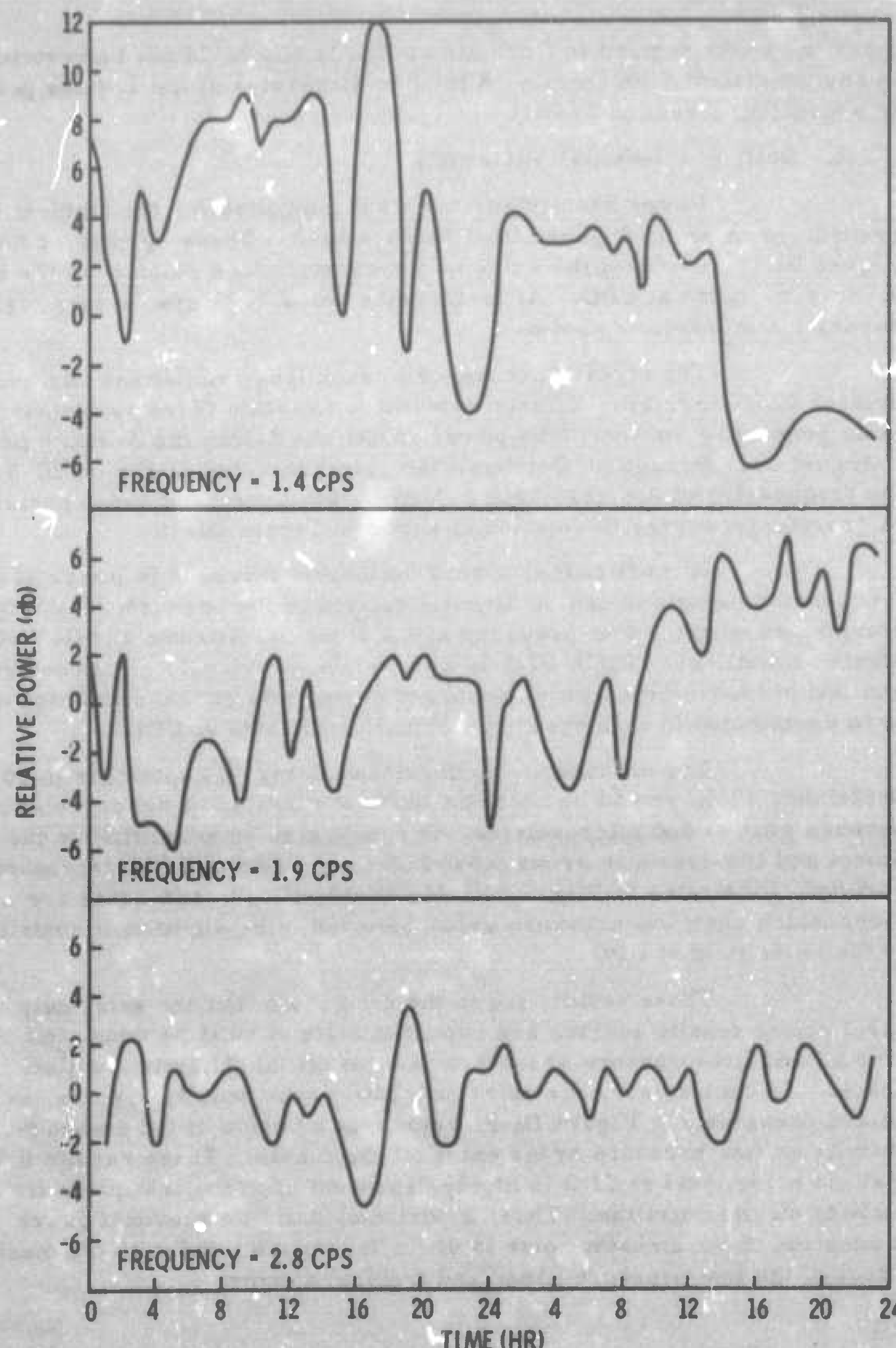

Figure III-7. CPO Peak Power Variations Over a 48-Hr Period

since the peaks seemed to fluctuate randomly and could not be restricted to any consistent time frame. A further discussion of the 1.4 cps peak is presented in Section IV-B1b.

2. Daily and Seasonal Variations

Power density spectra were computed for the ambient noise recordings shown in Figures III-1 through III-3. These spectra, compared in Figure III-8, represent the extreme power variations relative to the normal level of the noise at CPO. At frequencies below 1.75 cps, a very significant separation in power is shown.

The regular occurence of such large variations has been studied in great detail. Efforts were made to relate these variations to their generating source. The power variations during the 3-month period, 1 August 1965 through 30 October 1965, are presented in Figure III-9 for the frequencies of 0.5, 1.0, and 1.5 cps. The 4-sec and 3-sec period microseismic energy fluctuation is shown in Figure III-10.

In most cases, a very noticeable increase in power at the frequencies presented can be directly related to the occurrence of tropical storms and extreme low-pressure areas along the Atlantic and Gulf of Mexico coastlines. Table III-1 is a list of the previously mentioned storms and low pressure areas which occurred during this period and which may have contributed to an increased ambient noise level at CPO.

The occurrence of Hurricane Betsy, 2 September to 10 September 1965, should be noted as the best example of the correlation between storms and microseisms. It should also be noted that as the storm and low-pressure areas moved inland, the noise level decreased rapidly. Illustrated in Figures III-11, III-12, III-13, and III-14 are weather maps which show low pressure areas believed to be significant contributors to the noise field at CPO.

These results led to the conclusion that the extremely high-level power density spectra are representative of time periods when tropical storms and low-pressure areas are present off the Atlantic and Gulf coasts. In comparison, the extremely low-power density spectra, as presented previously in Figure III-8, represent a period of time when no storm activity or low pressure areas exist off the coasts. These results indicate that the noise level at CPO is highly dependent upon the low pressure activity off the coastline. Thus, a periodic, daily or seasonal power fluctuation of the ambient noise is difficult to establish due to the masking effect of the low pressure areas and tropical storms.

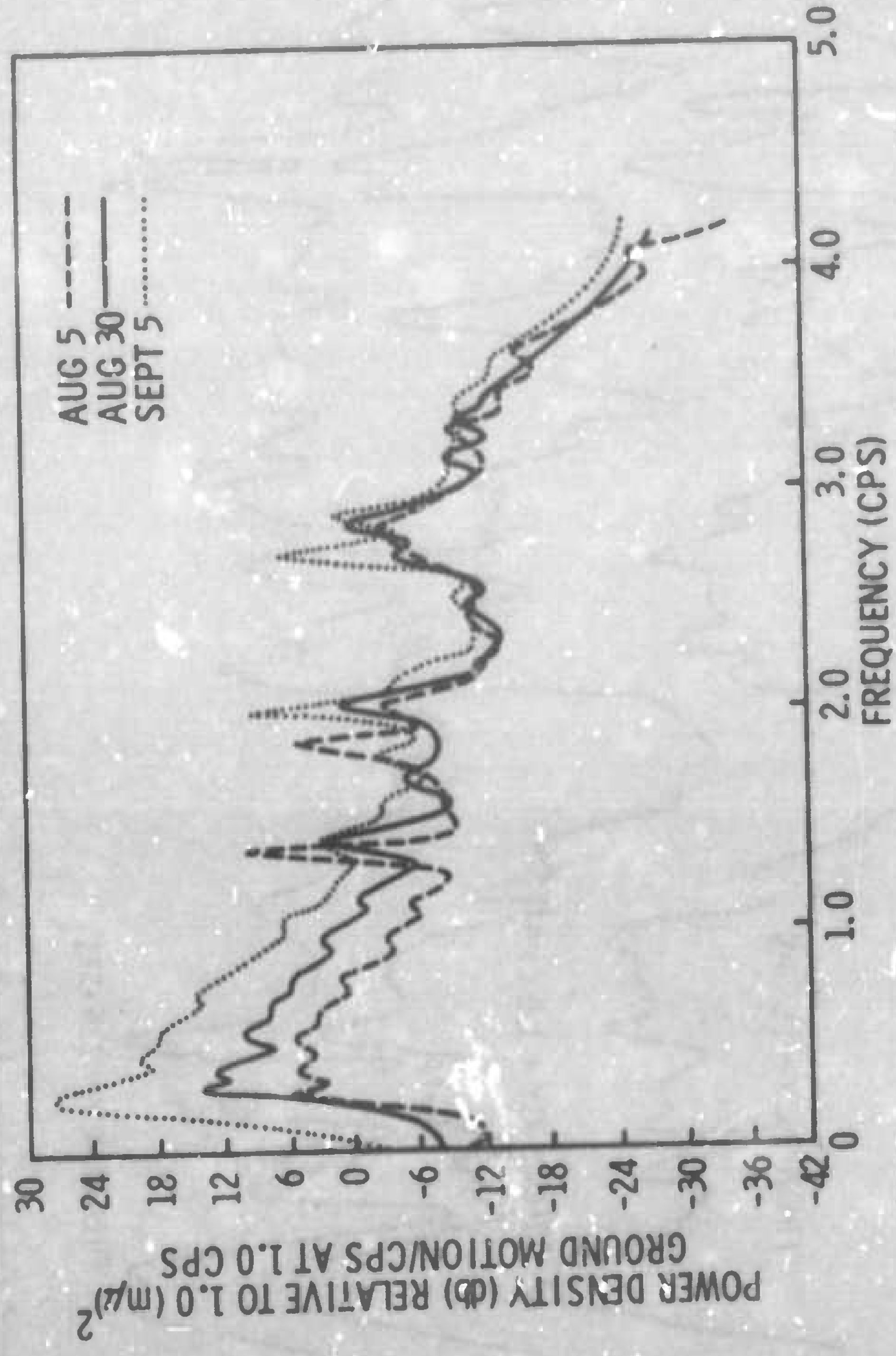

Figure III-8. CPO Noise Power Density Variations

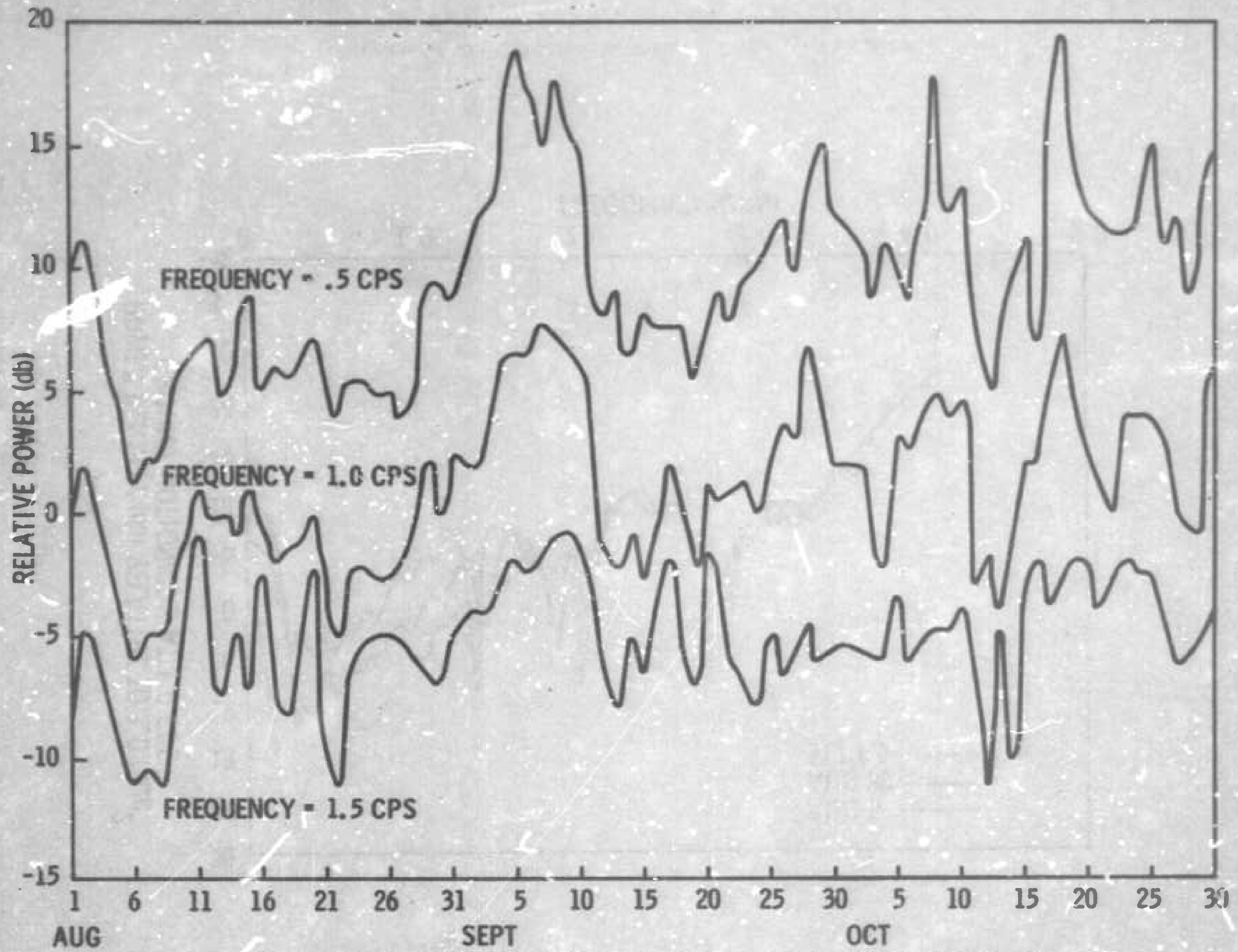

Figure III-9. CPO Noise Power Variations Over a Three-Month Period

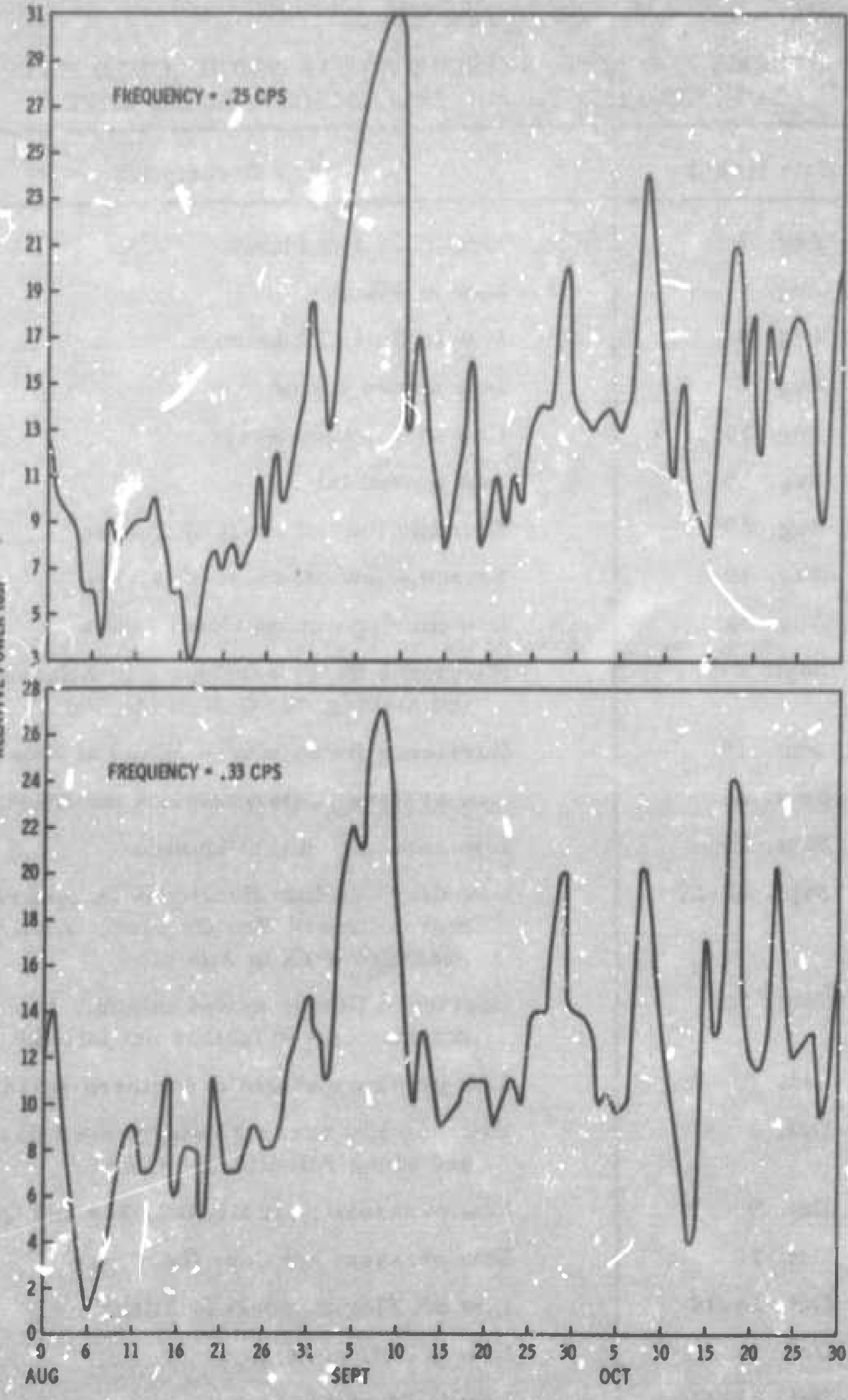

Figure III-10. CPO Noise Power Variations of 4- and 3-Sec Period Microseisms Over a Three-Month Period

Table III-1

STORMS AND LOW PRESSURE AREAS WHICH COULD HAVE CONTRIBUTED TO THE CPO AMBIENT NOISE LEVEL

Date (1965)	Description
Aug. 1	Low in Gulf of Mexico
Aug. 2	Low in Atlantic
Aug. 3	Low in Gulf of Mexico
Aug. 4	Low moved inland
Aug. 15	Low at Cape Hatteras
Aug. 16	Low moved inland
Aug. 29	Extreme low off coast of Quebec
Aug. 30	Extreme low off coast of Quebec
Aug. 31	Low moving across Great Lakes
Sept. 2-9	Hurricane Betsy developing in Atlantic and moving into Gulf of Mexico
Sept. 10	Hurricane Betsy moves inland at New Orleans
Sept. 24	Low at Cape Hatteras and in the Atlantic
Sept. 25	Low entering Gulf of Mexico
Sept. 26-29	Low develops into Hurricane Debbie as it moves toward New Orleans. Also low pressure area in Atlantic
Sept. 30	Hurricane Debbie moved inland. Low in Atlantic moved further out into the Atlantic
Oct. 4	Low pressure storm in northern Atlantic
Oct. 8	Extreme low pressure storm over Great Lakes and along Atlantic coastline
Oct. 9	Low pressure near Great Lakes and Quebec
Oct. 10	Low pressure off Cape Hatteras
Oct. 16-18	Low off Florida coast in Atlantic
Oct. 19	Low in Gulf of Mexico
Oct. 21-22	Low in Atlantic
Oct. 23	Low off Cuba coast

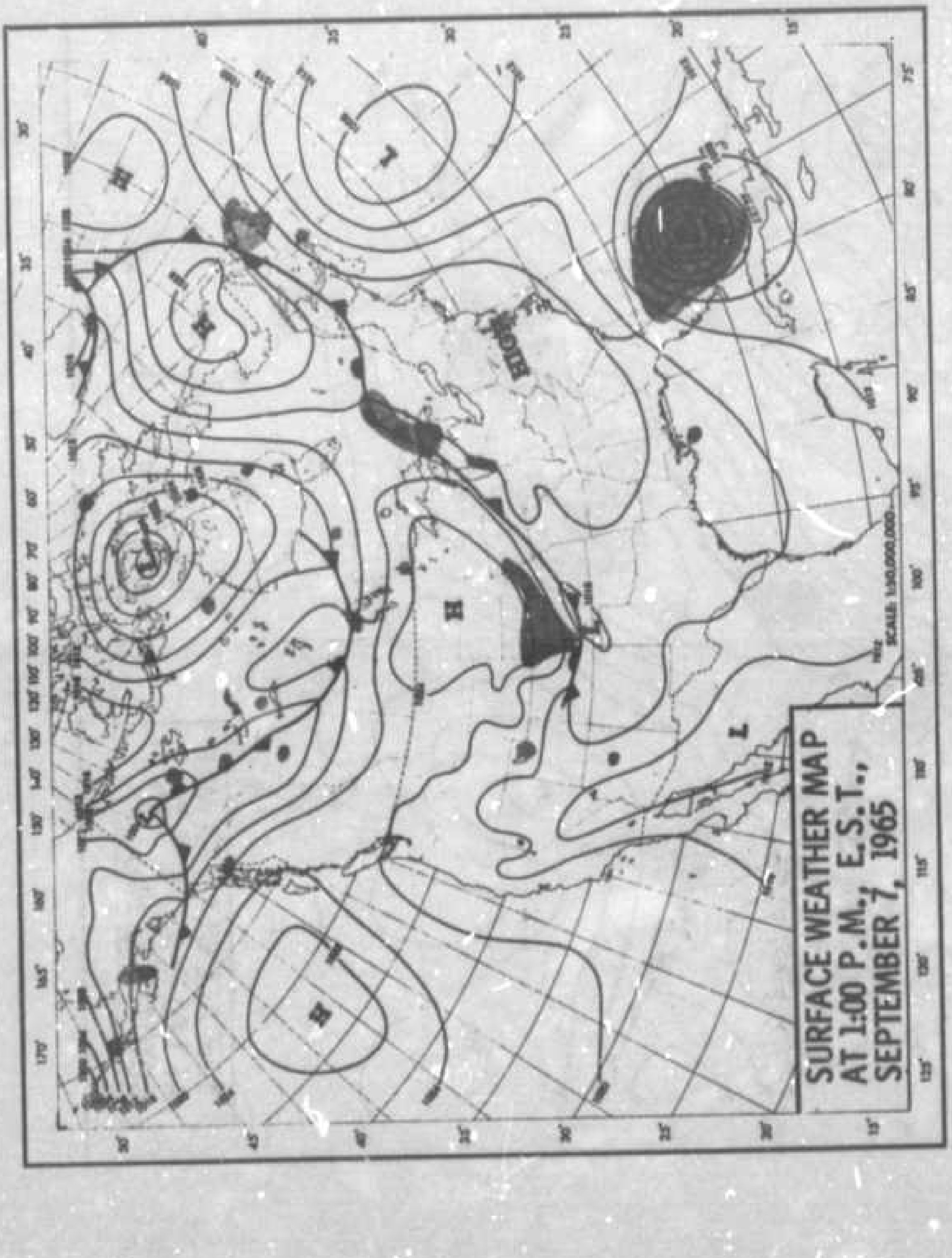

Figure III-11. Surface Weather Map at 1:00 P.M., E.S.T., 7 September 1965

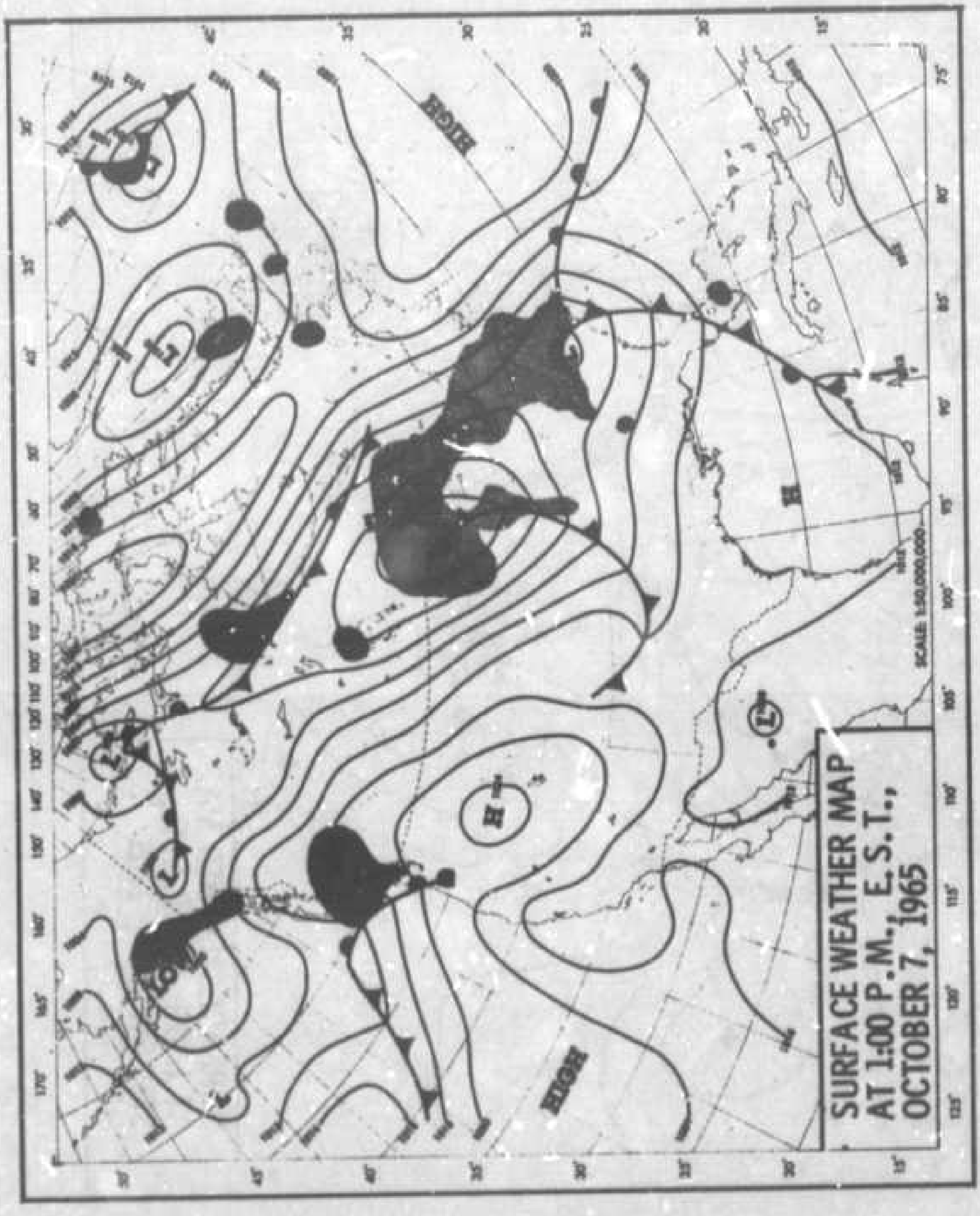

Figure III-12. Surface Weather Map at 1:00 P.M., E.S.T., 7 October 1965

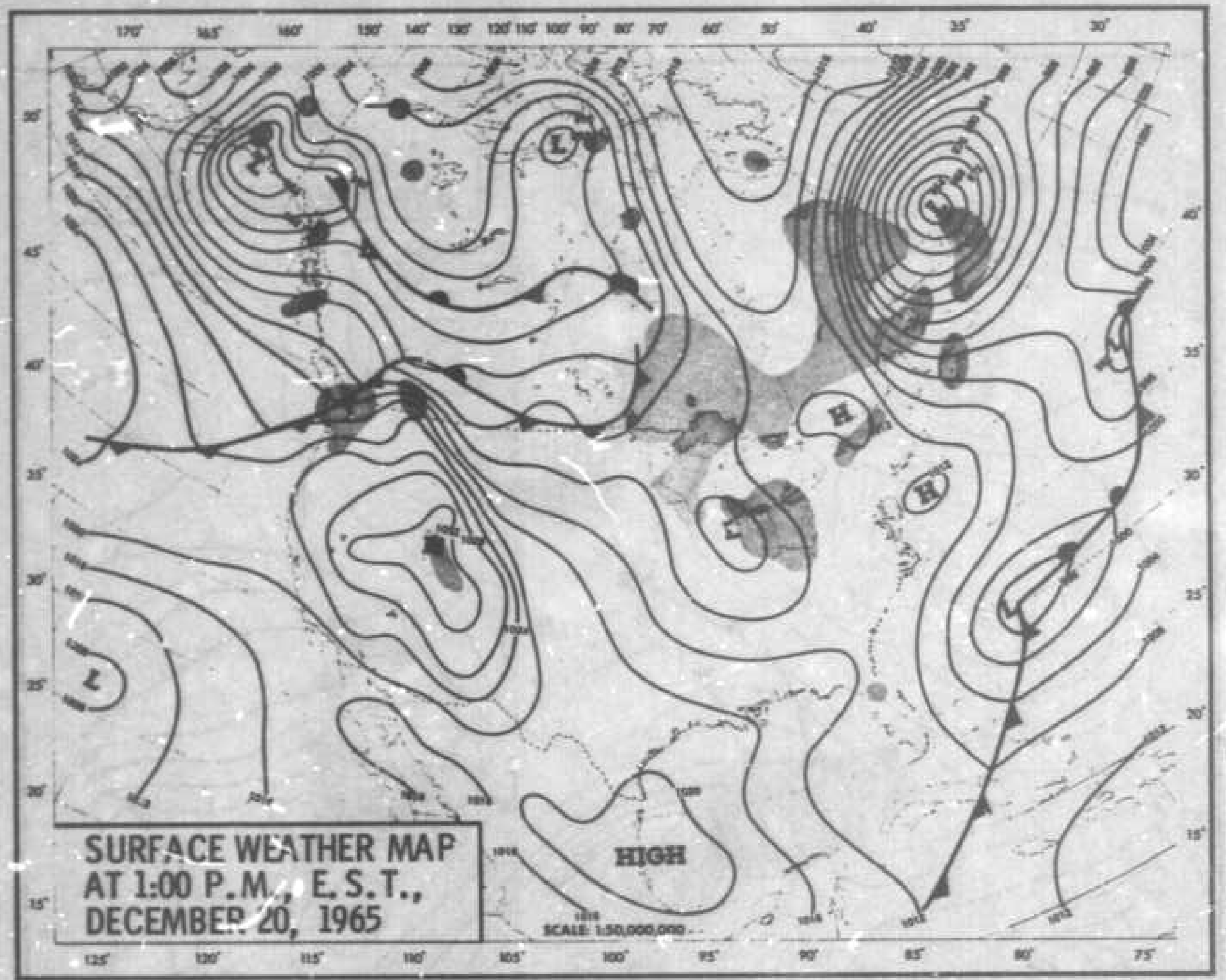

Figure III-13. Surface Weather Map at 1:00 P.M., E.S.T., 20 December 1965

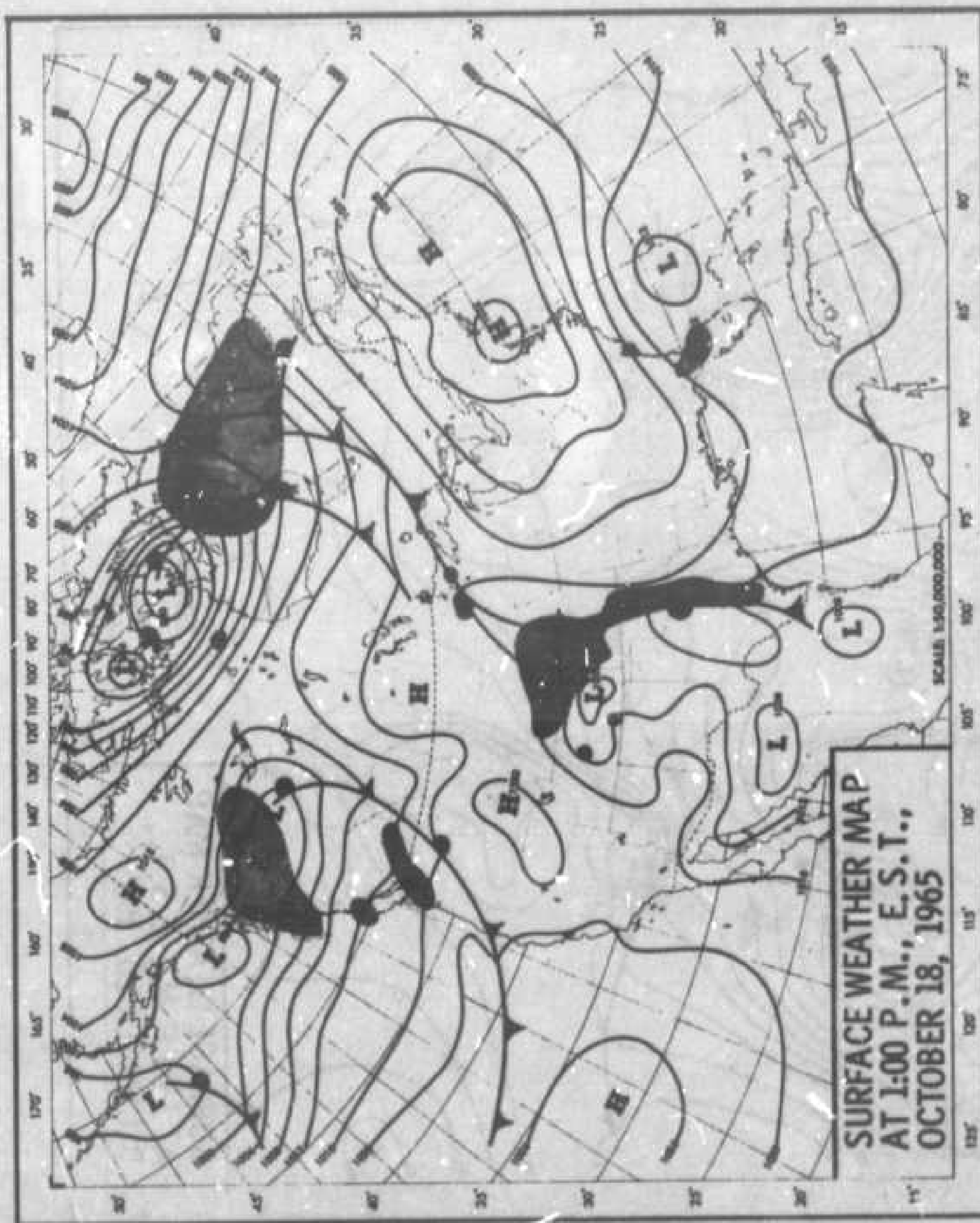

Figure III-14. Surface Weather Map at 1:00 P.M., E.S.T., 18 October 1965

SECTION IV

CPO MULTIDIMENSIONAL AMBIENT NOISE FIELD

This section presents an analysis of the organized noise field existing at CPO which was made by considering the spatially organized noise at various frequencies on the basis of its apparent horizontal velocity and direction of propagation across the array. In the previous section, it was shown that the ambient noise level at CPO changed significantly during several given time periods. This section presents the frequency-wavenumber spectra of the spatially organized noise field for frequencies of 0.5 to 2.0 cps at 0.5 cps increments for the different ambient noise levels.

A. PREDICTION FILTERING

1. Introduction

Prediction filters were designed for various selected samples of data. Applying the prediction filter to the data from which it was designed gives a measure of the spatially coherent noise. Subtracting the predicted noise from the ambient noise recorded at the given location in the array leaves an estimate of the unpredictable ambient noise. The percentage of unpredictable noise as a function of frequency can then be obtained by taking the ratio between the power density spectra of the unpredictable noise to the power density spectra of the total noise. For the CPO array, the center seismometer, Z10, was used for prediction purposes.

2. Results

Prediction filtering results for May, June, July, August, October, November, and December 1965 are shown in Figure IV-1. For all results, excluding August and December, the percentage of spatially coherent noise resolved by the 10-element array does not change significantly for all frequencies greater than 0.25 cps except for the frequency of 1.4 cps which has shown a variation as large as 12 db between two given noise samples. Otherwise, the prediction error power spectrum for given frequencies within this band varied only 1 to 4 db, which is probably attributed to a change in the local, random noise field. However, the prediction filter designed from and applied to the low-level ambient noise recorded 6 August 1965 showed a decrease in the percentage of spatially organized noise. Also, the prediction filter designed from and applied to the high-level noise sample from 21 December 1965 showed an increase in the percentage of spatially organized noise which is almost equivalent to the increase in power of the high-level noise.

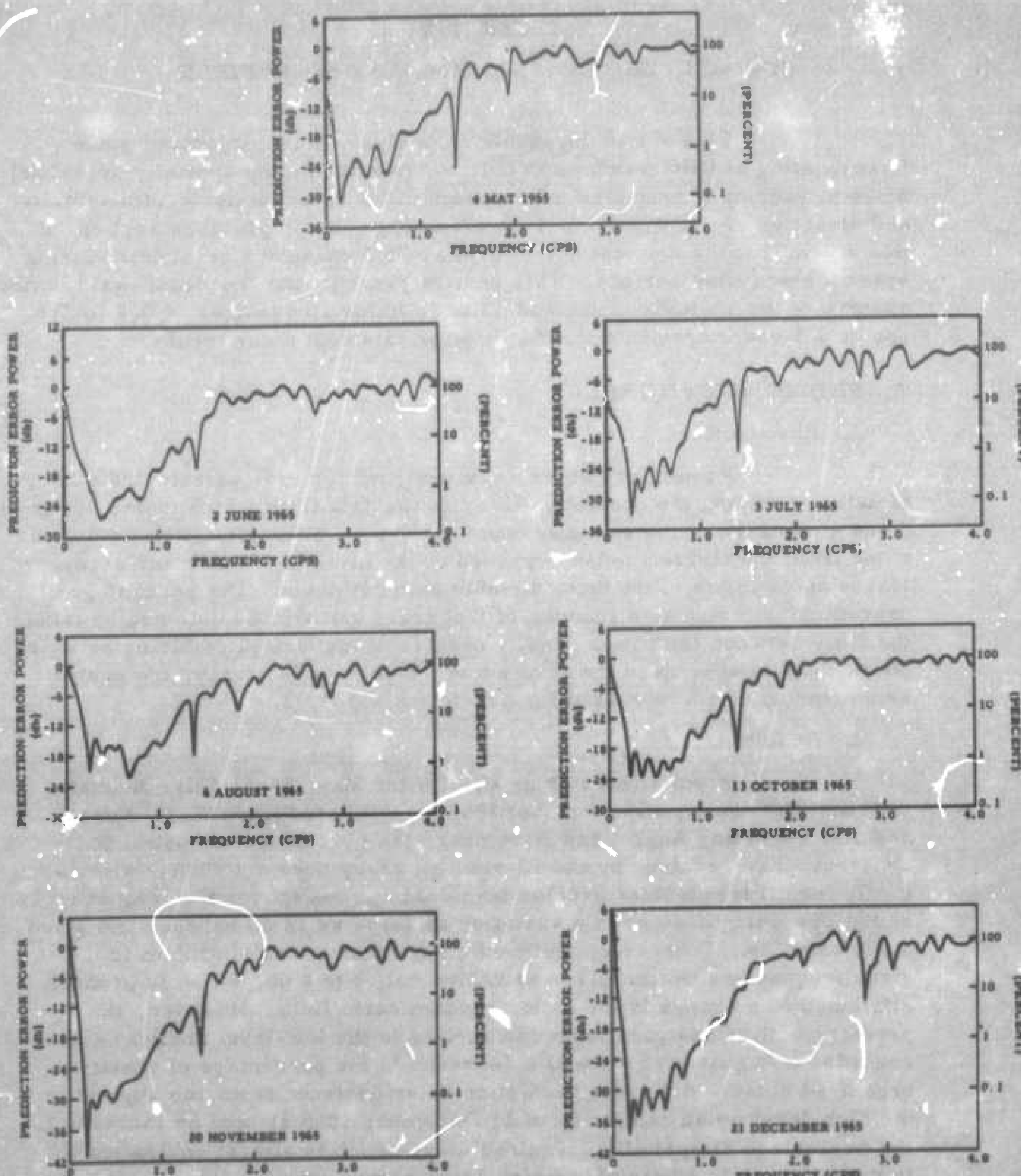

Figure IV-1. Percent Prediction Error for Seven CPO Noise Samples

A comparison of the percentage of predictable noise for the two extreme noise levels is shown in Figure IV-2. The comparison of these with previous normal noise level results indicates that the fluctuating noise power is predictable and spatially organized. Also, the increase in percentage of predictable noise can be detected at frequencies as high at 1.75 cps, as will be shown more clearly in the subsection covering frequency-wavenumber spectra.

B. FREQUENCY-WAVENUMBER SPECTRA

Sets of frequency-wavenumber spectra were computed at various intervals during the recording period of this contract. Noise samples were selected from each of the different noise levels previously discussed. Table IV-1 is a brief description of the noise samples from the 1965 and 1966 data used to compute the sets of 18 frequency-wavenumber spectra. Figures IV-3 through IV-6 present 12 sets of frequency-wavenumber spectra computed for the 10-channel noise recorded at CPO. The following paragraphs present a discussion of the individual lobes over given frequency bands and for the different noise levels.

1. Coherent Noise Lobes

a. Lobe 18

The predominant coherent noise lobe at the lower frequencies (1.0 cps and below) is denoted as lobe 18. Estimates of the apparent horizontal velocities across the array of the spatially organized noise at these frequencies cannot accurately be determined from the frequency-wavenumber spectra due to the limited resolution of the array; however, a directionality in the coherent noise can be detected. The lobe is usually shifted to the north and west, indicating that the predominant contributor, other than mantle P-wave energy, is probably microseismic energy generated in the area of the Atlantic and Gulf coastlines. Frequency-wavenumber spectra, computed from normal-level noise samples, show this lobe at frequencies as high as 1.5 cps, although the lobe is not a strong contributor to the coherent noise field at 1.5 cps.

Previous prediction filtering results indicated that the increase in noise power was spatially coherent; therefore, a change in the lobe or lobes representing this noise should be evident. This is the case for lobe 18, which fluctuates with the noise level.

A higher recorded noise level shifts the lobe further from the center of the frequency-wavenumber spectra. This indicates that a large portion of the increased coherent noise is low velocity. Under the high noise level, the peak point of the lobe is consistently at 4 km/sec

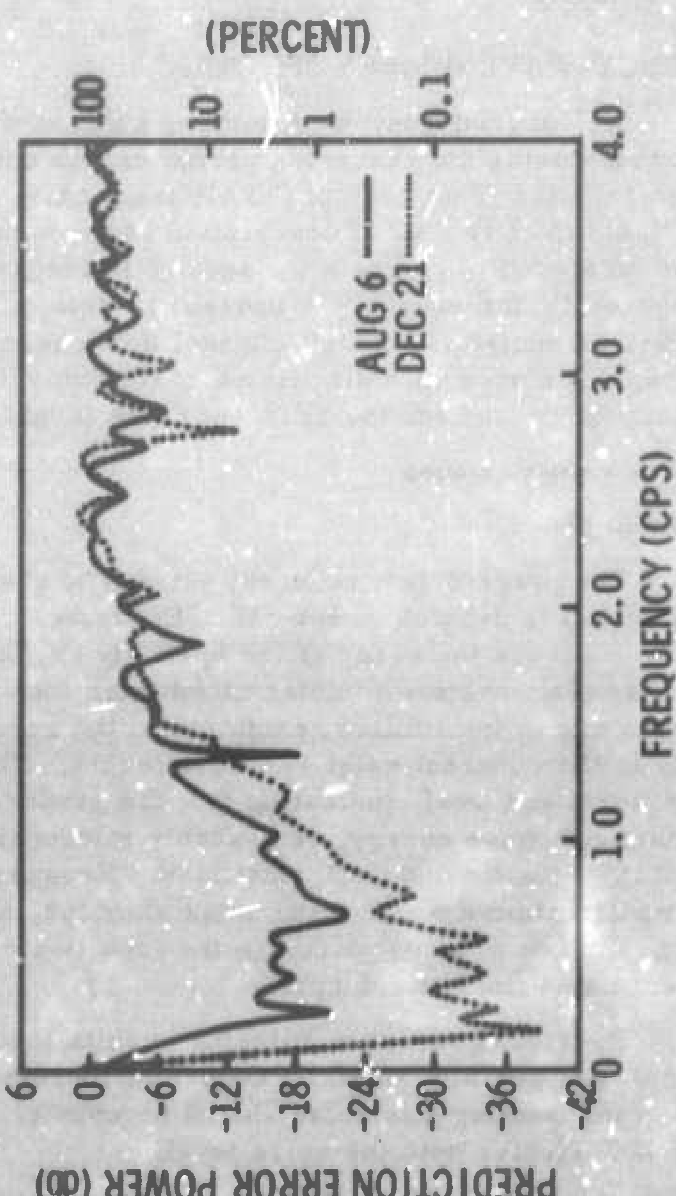

Figure IV-2. Percent Prediction Error for 6 August 1965 and 21 December 1965

Table IV-1

NOISE USED TO COMPUTE WAVENUMBER SPECTRA

Date (1965)	Record Start Time (GCT)	Noise Level
May 1	00:00:00	Normal
May 4	02:58:45	Normal
May 8	06:55:00	Normal
May 12	11:00:12	Normal
May 16	19:58:35	Normal
May 20	08:00:20	Normal
May 24	22:03:15	Normal
June 2	04:57:10	Normal
July 3	02:00:00	Normal
July 7	08:19:00	Normal
July 10	09:18:40	Normal
July 14	13:14:00	Normal
July 17	15:00:00	Normal
July 20	19:56:30	Normal
July 23	23:03:10	Normal
Aug 6	04:01:15	Low
Sept 5	11:02:00	High
Sept 8	13:58:45	High
Sept 11	15:59:00	Normal
Sept 15	01:01:50	Normal
Sept 21	02:01:36	Normal
Sept 28	09:01:34	High
Oct 13	11:00:00	Below normal
Oct 18	14:07:00	High
Nov 20	23:10:45	Normal
Dec 21	03:01:00	High
Date (1966)		
Jan 9	08:05:45	Normal
Jan 22	22:15:24	High
Feb 19	22:58:40	High
Feb 27	07:05:29	Normal
Mar 15	22:33:16	High
Apr 1	12:23:17	Normal
May 2	01:00:00	Normal
June 6	07:00:00	Normal
July 5	10:21:00	Normal
Aug 18	05:58:41	Normal
Sept 28	20:15:02	Normal
Oct 15	11:17:42	High

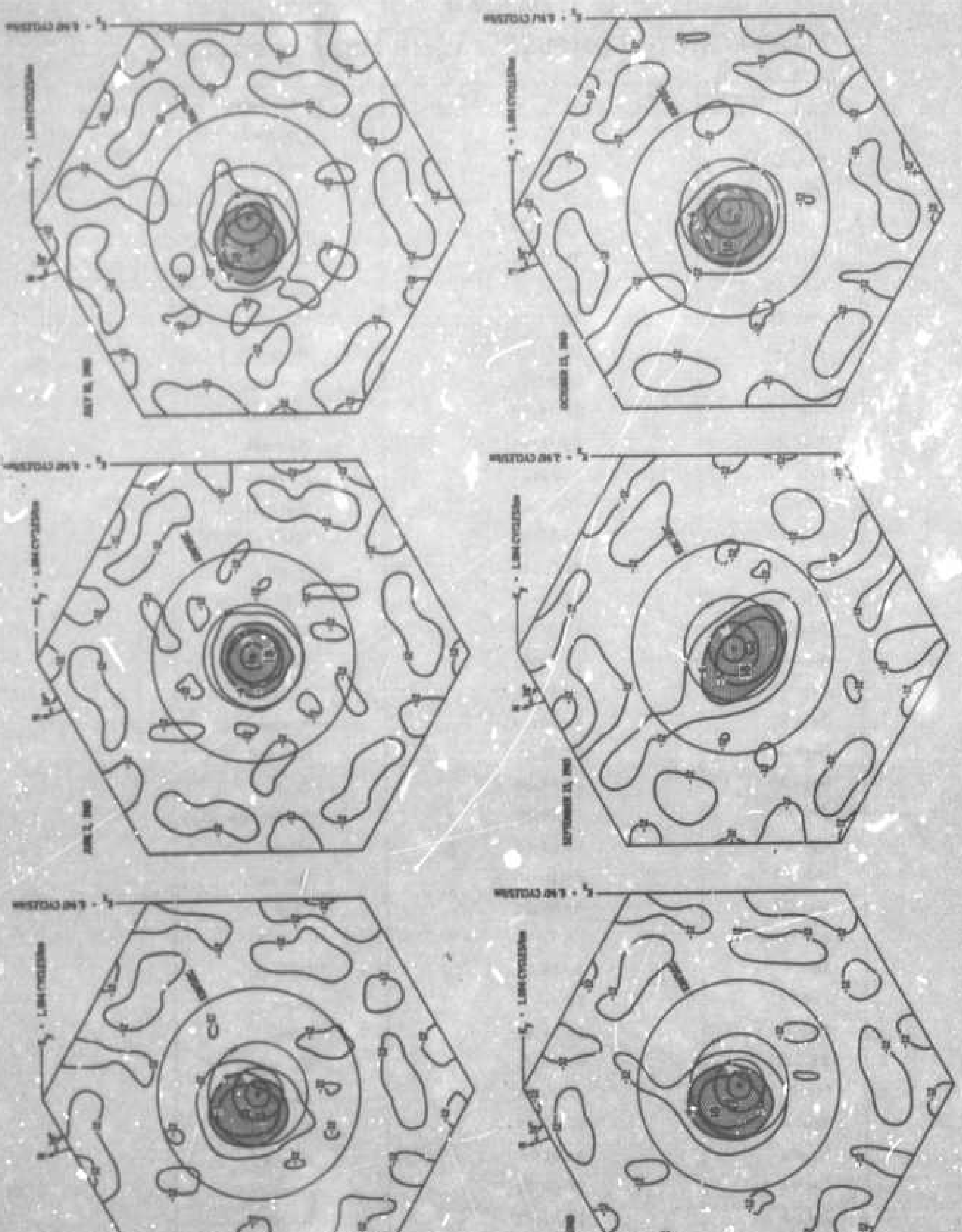

Figure IV-3a. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to Pctpber 1966 (f=0.5 cps)

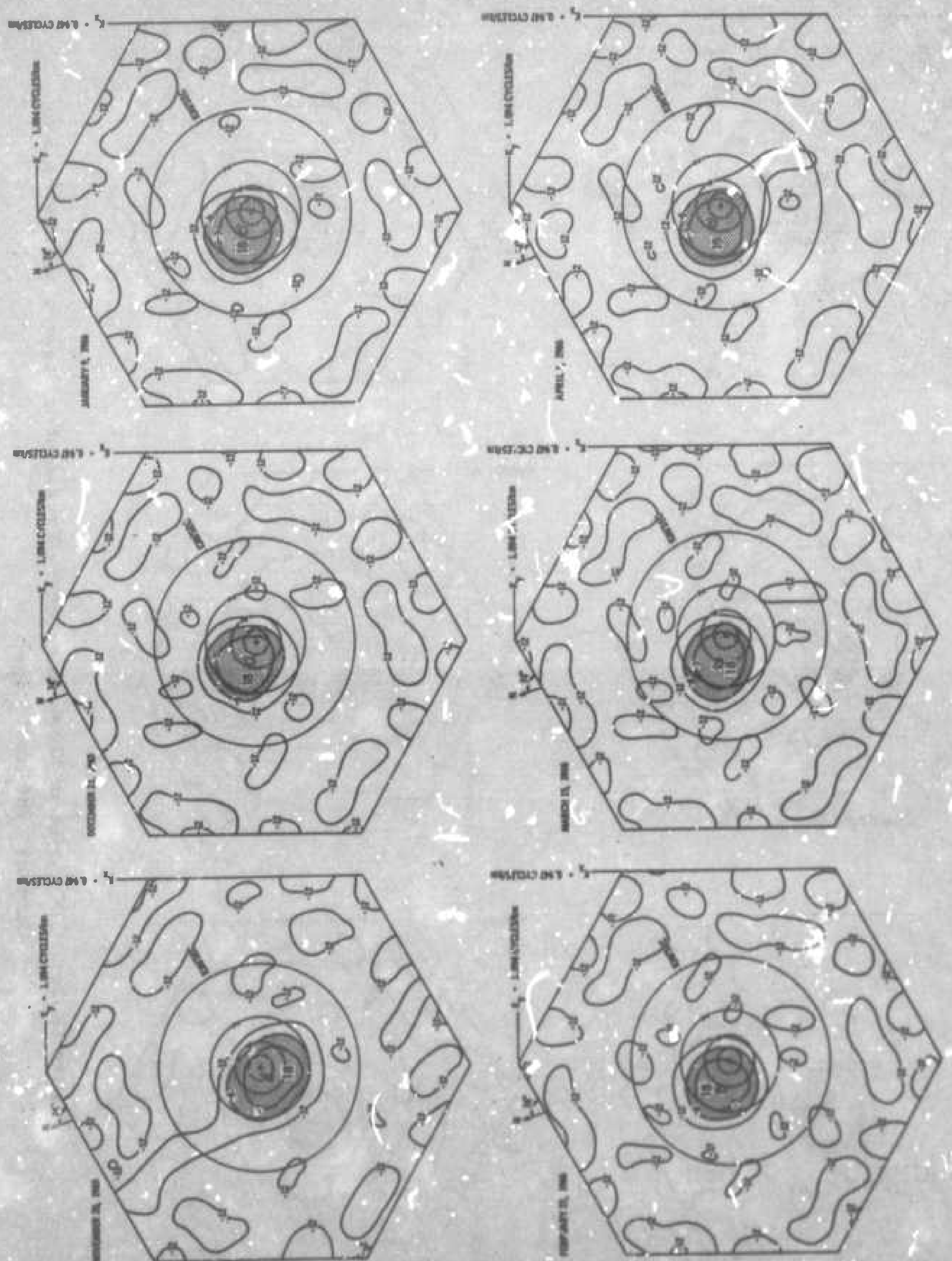

Figure IV-3b. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=0.5 kps)

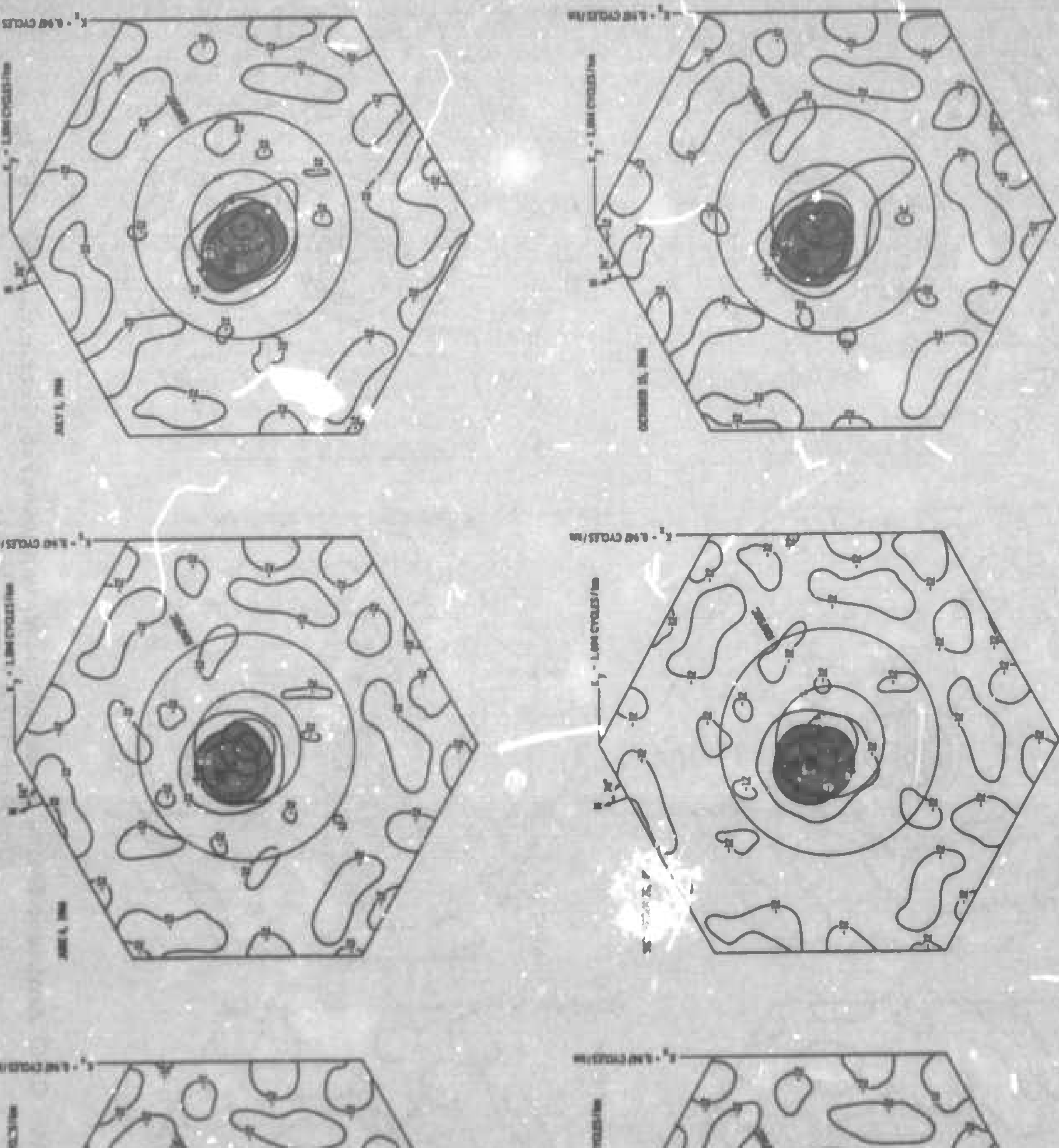

Figure IV-3c. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=0.5 cps)

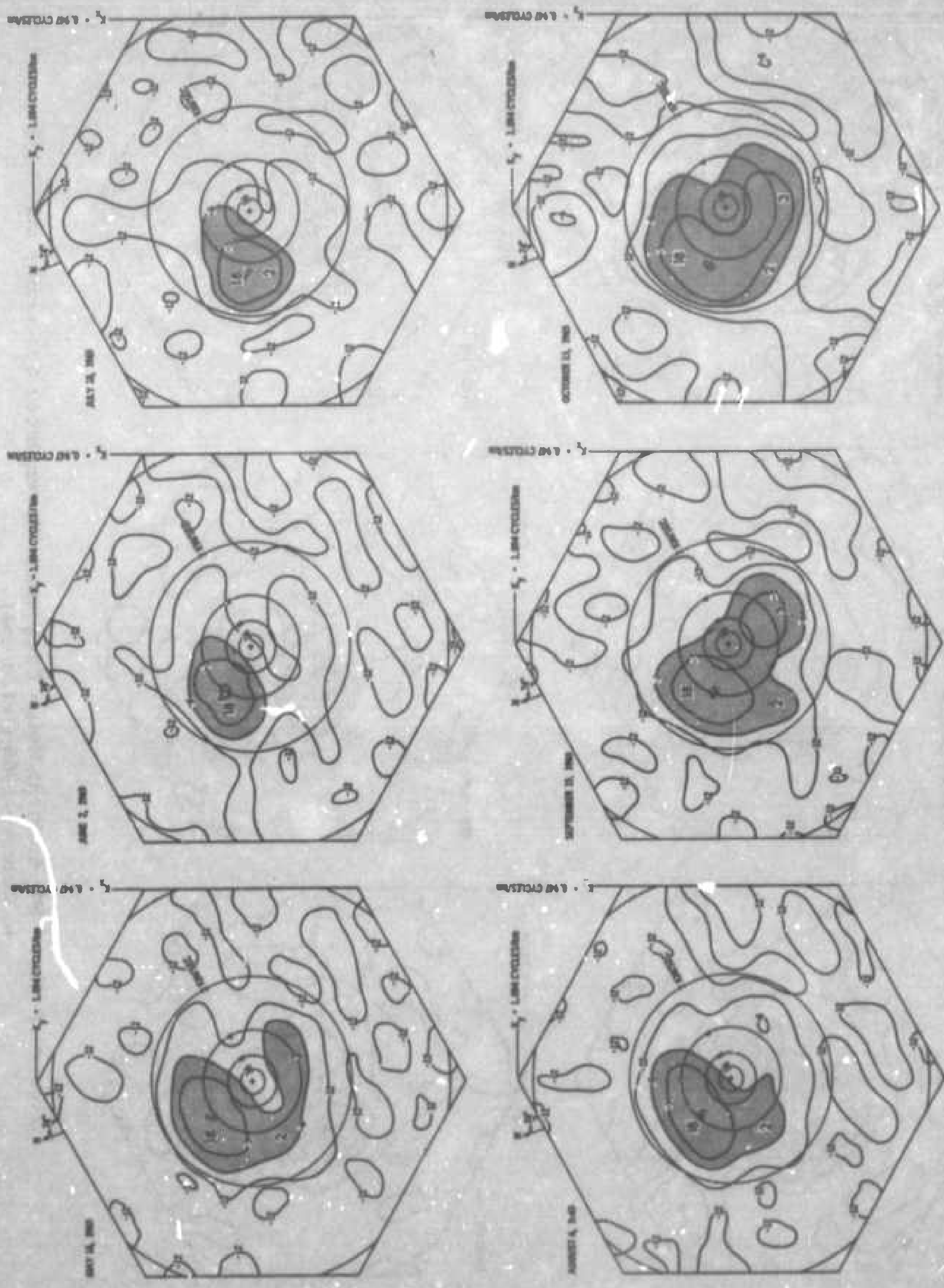

Figure IV-4a. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.0 cps)

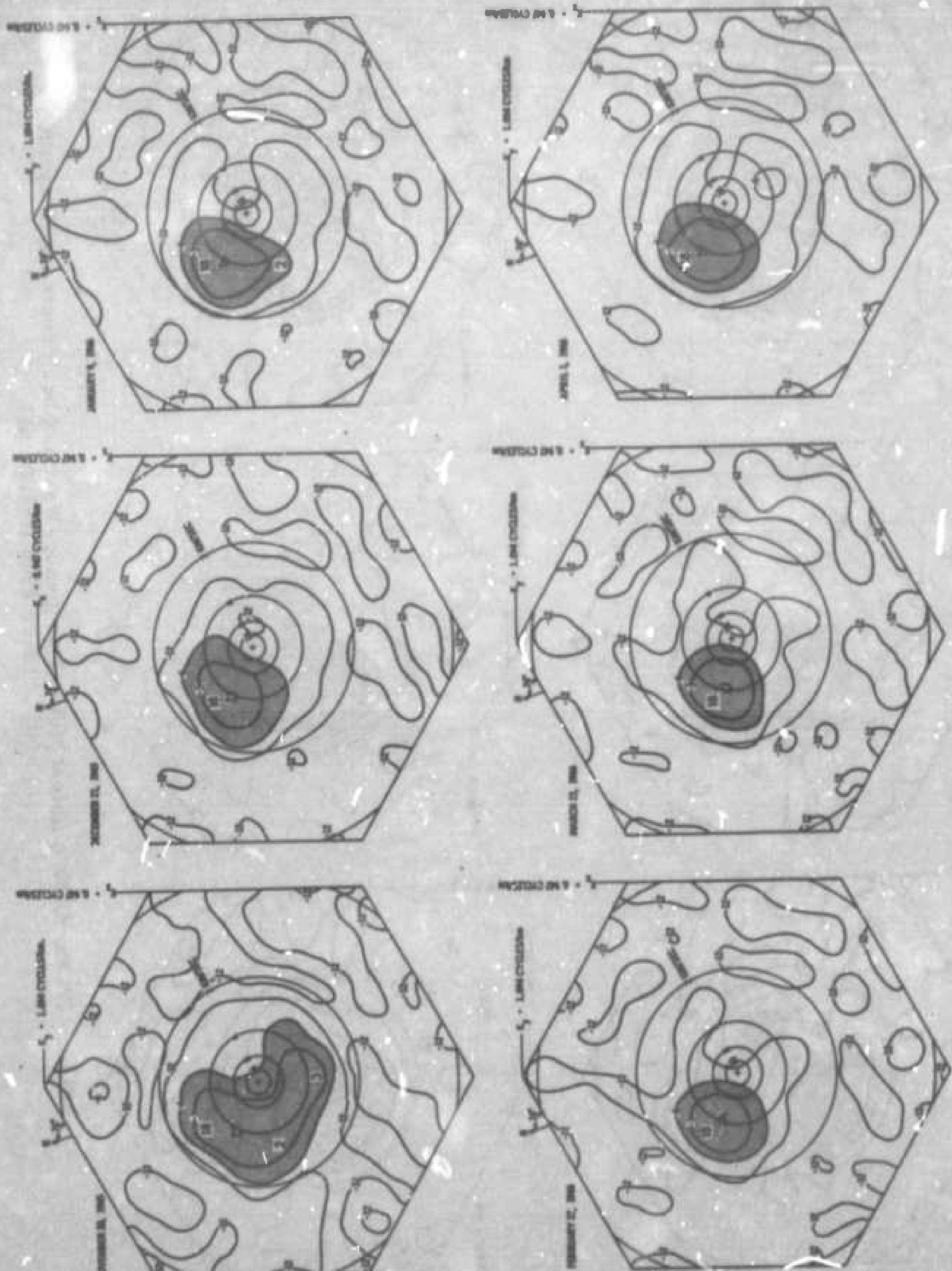

Figure IV-4b. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.0 cps)

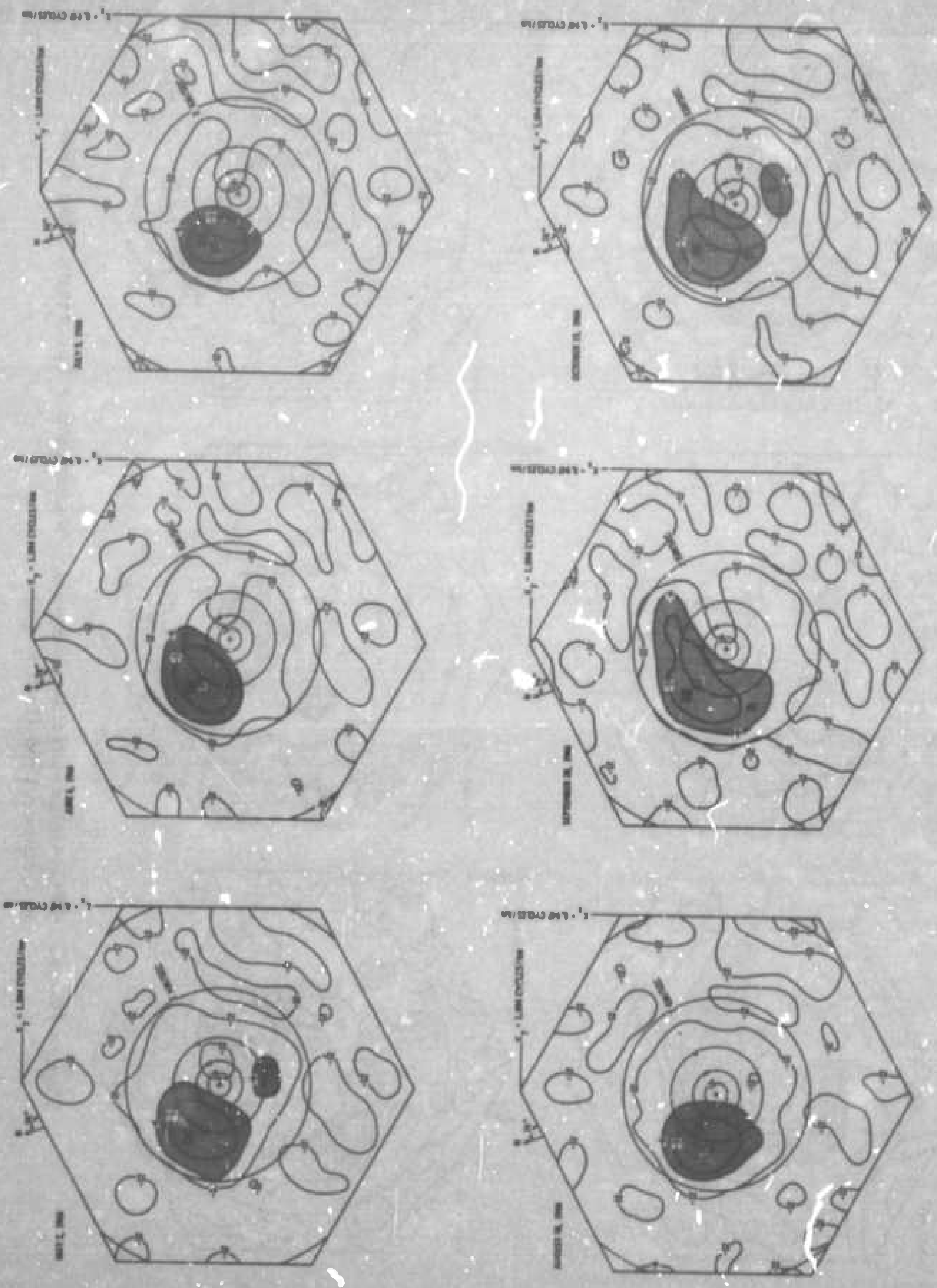

Figure IV-4c. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.0 cps)

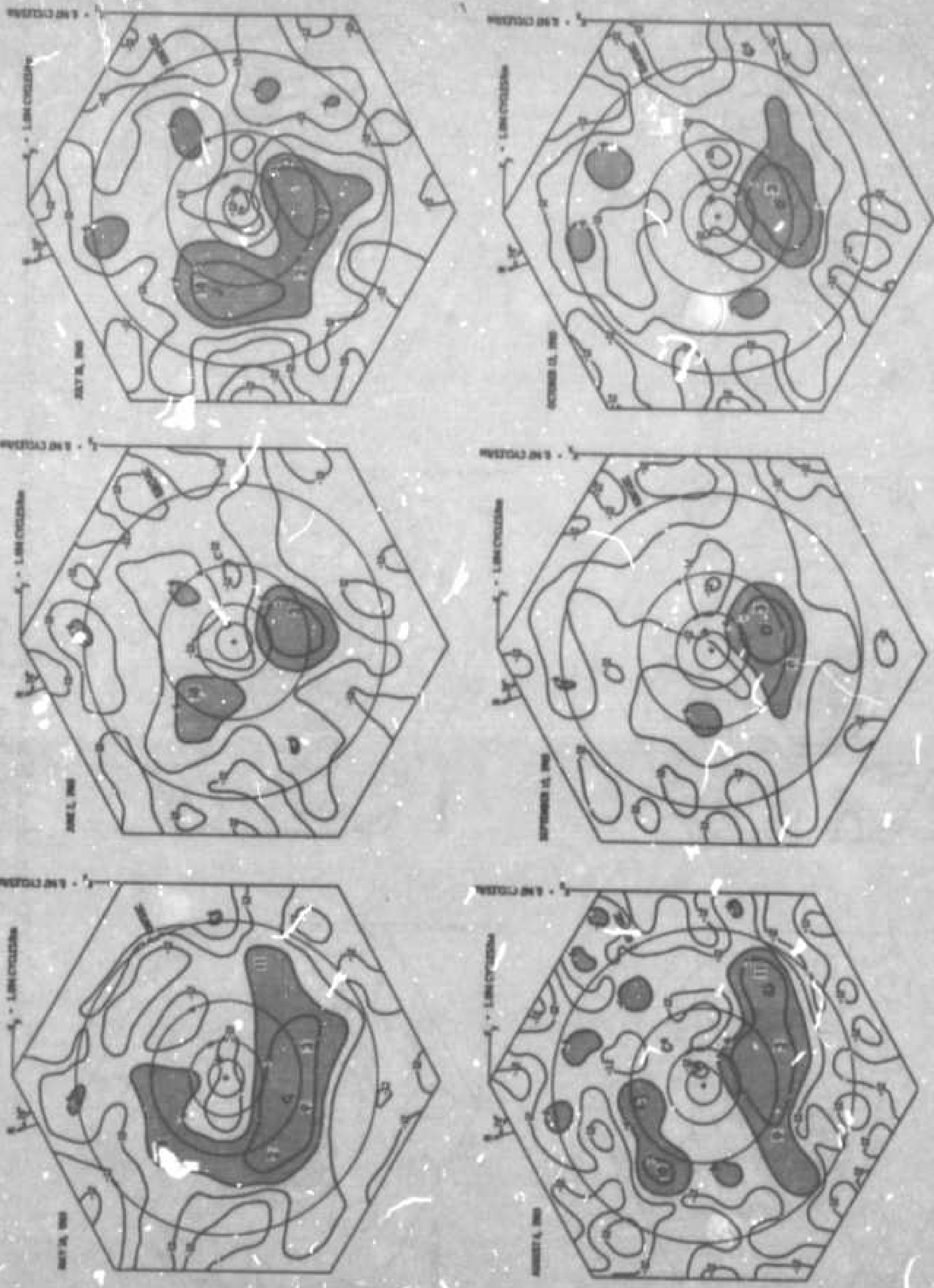

Figure IV-5a. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.5 cps)

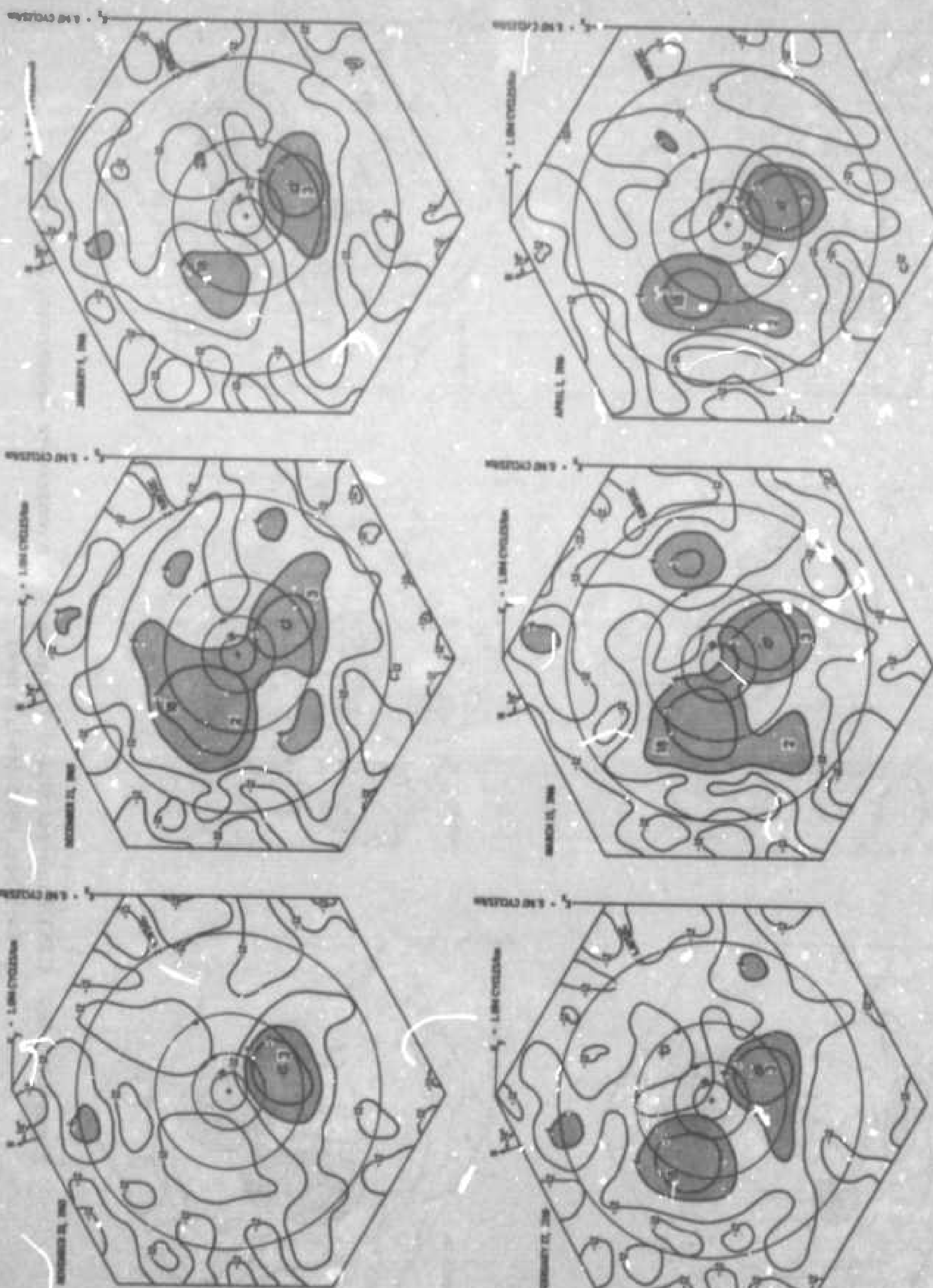

Figure IV-5b. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.5 cps)

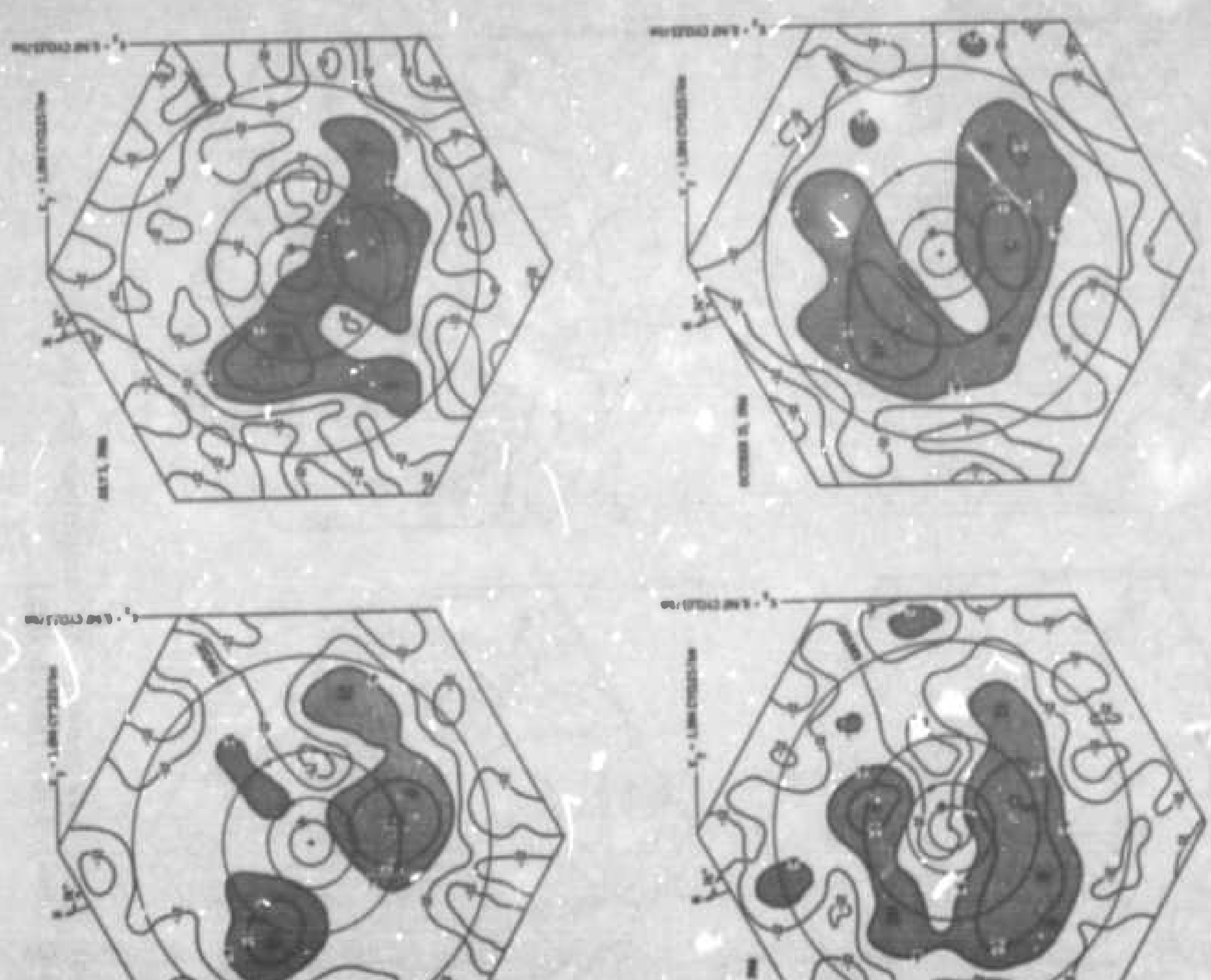

Figure IV-5c. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.5 cps)

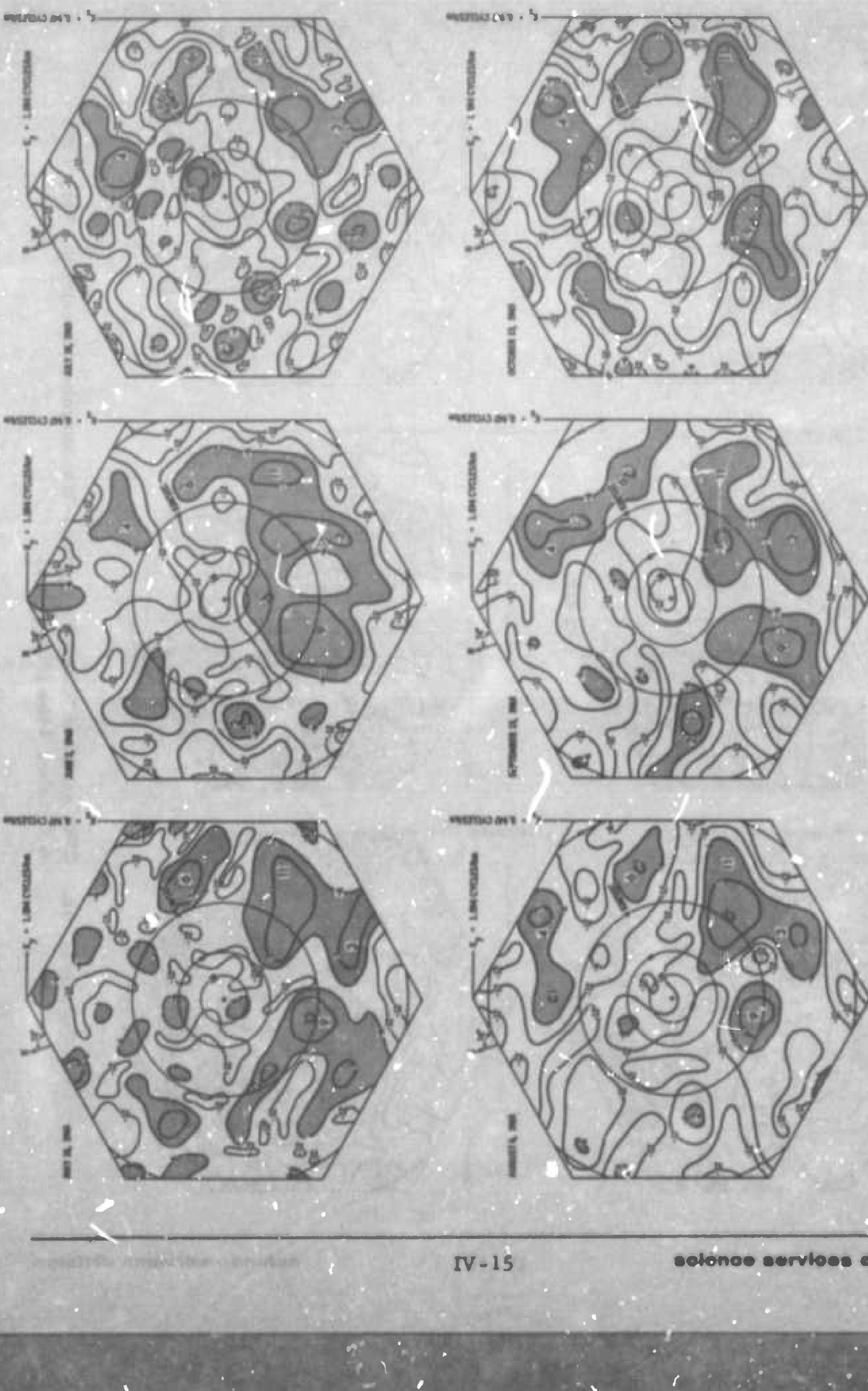

Figure IV-6a. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=2.0 cps)

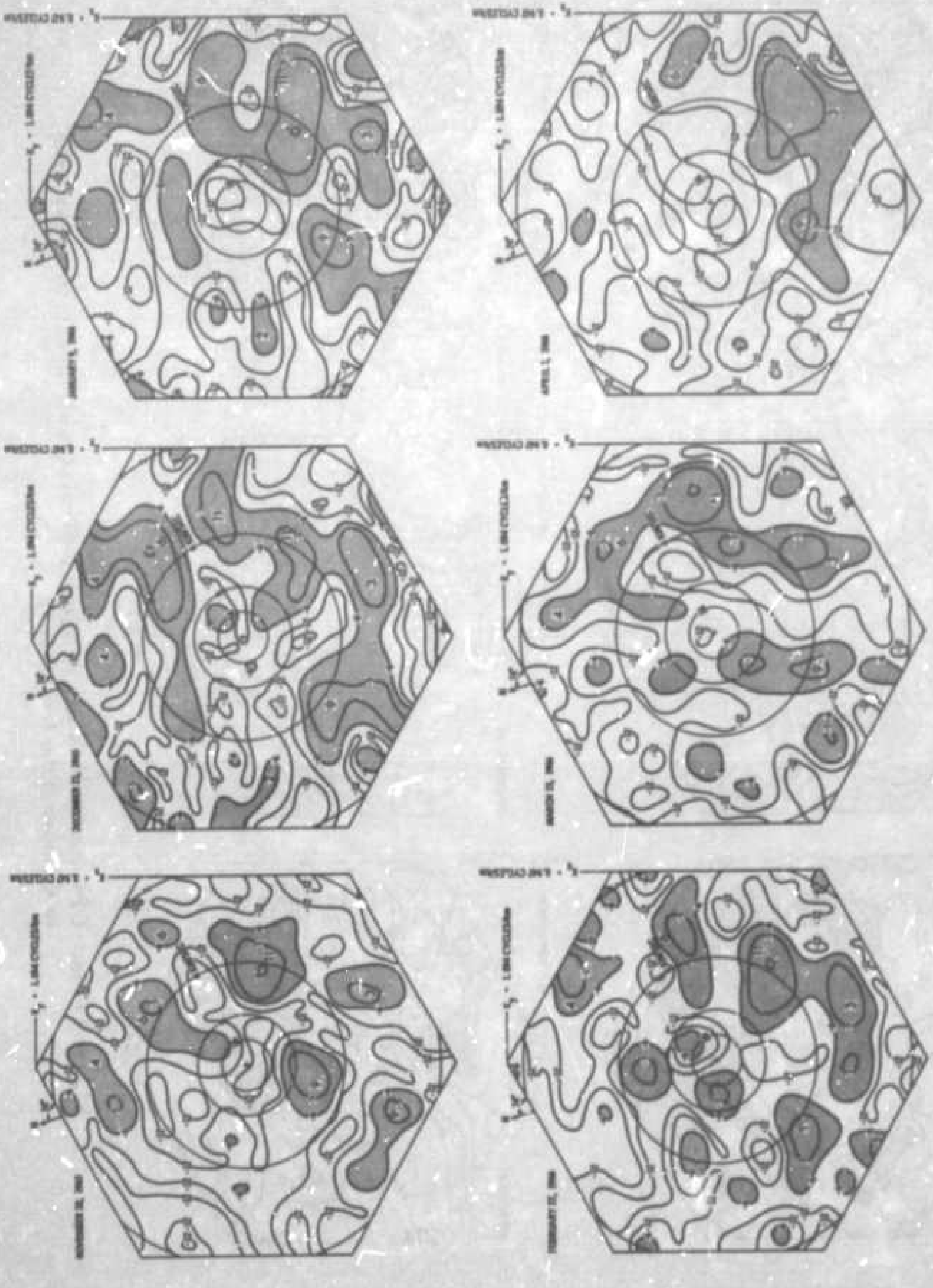

Figure IV-6b. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=2.0 cps)

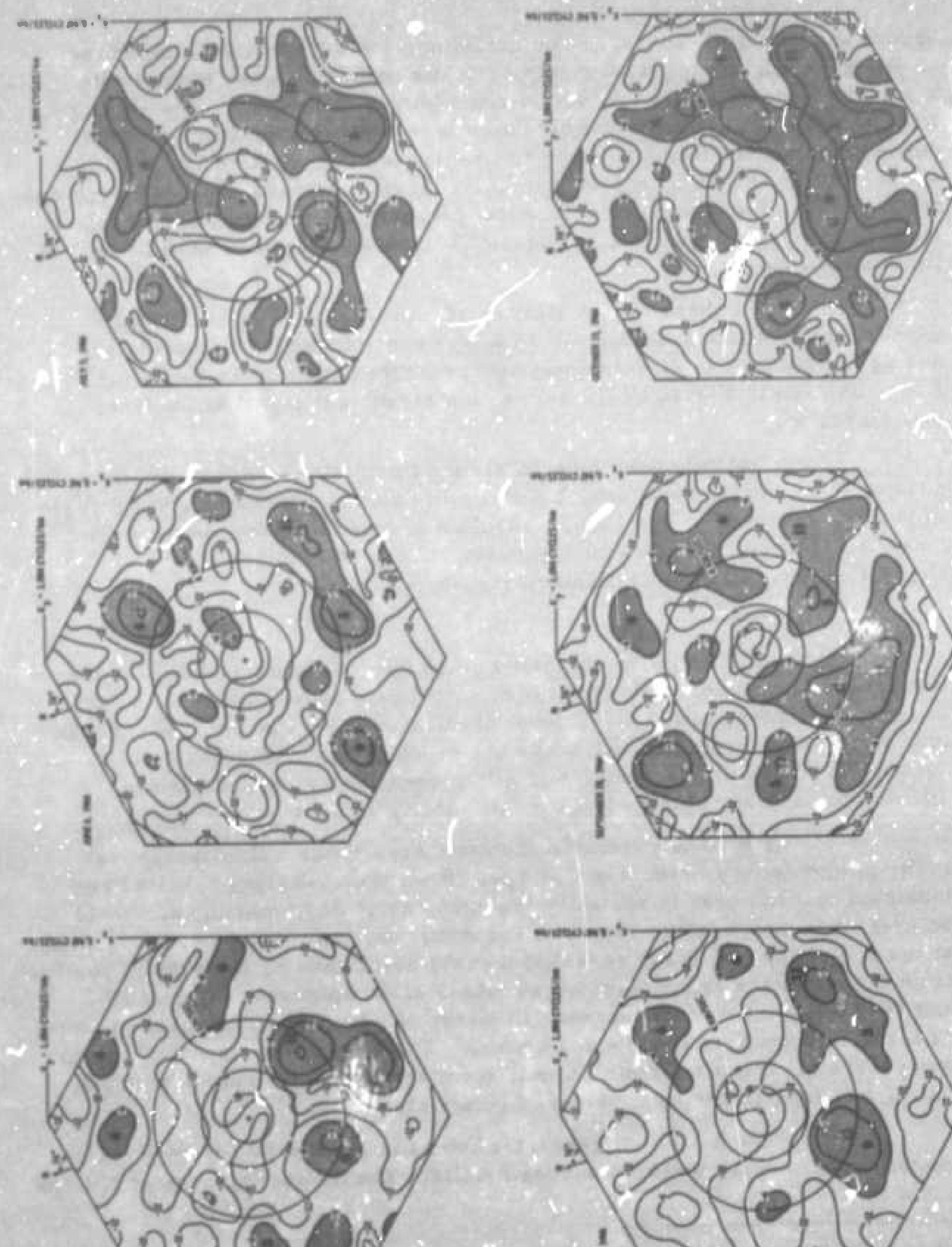

Figure IV-6c. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=2.0 cps)

apparent horizontal velocity. The actual horizontal velocity of this noise is probably slightly lower than this since the mantle P-wave energy with a velocity greater than 8 km/sec is contributing to the lobe. The shift of the lobe is always either from the direction of the Atlantic or Gulf coastline depending upon the location of the low pressure areas or tropical storms which correspond with the increased noise level. The f-$\vec{k}$ spectra at 0.5 cps for December was computed with a low pressure area in the Atlantic coast region, as shown previously in Figure III-13, and exhibits a shift in the location of lobe 18.

Furthermore, a shifting of this lobe southward in the frequency-wavenumber spectra, for 20 November 1965 which was computed during the passage of an extremely low pressure area across the Great Lakes as seen in Figure IV-7, indicates a significant contribution from that direction.

Not only does lobe 18 show a fluctuation in direction corresponding to low pressure areas, but it also exhibits a corresponding increase in power. Under high-level noise conditions, lobe 18 is the predominant noise lobe through 1.5 cps and a significant contributor at 1.75 cps as shown in Figure III-5 of CPO Quarterly No. 3.*

b. Lobe 3

The spatially organized noise lobe, denoted as lobe 3 in the frequency-wavenumber spectra, is generated by a source to the north of the array. Under normal noise level conditions, lobe 3 is much lower than lobe 18 at frequencies below 1.0 cps but becomes the predominant contributor at 1.50 cps. Lobe 3 exists at all frequencies above 1.0 cps and appears to have an apparent horizontal velocity of 3.0 to 4.0 km/sec.

Previously mentioned in this report was a fluctuating peak in the power density spectra at 1.4 cps. Prediction filtering results have indicated that the peak is spatially organized noise and, therefore, should be evident in wavenumber space. Frequency-wavenumber spectra computed at the frequency of 1.4 cps revealed that the noise causing the peak is coming from the north and is represented as lobe 3 in the spectra. Figures IV-8 and IV-9 show the evident increase in power of lobe 3 when compared to lobe 18 for data containing the 1.4 cps energy. The wavenumber spectra for this study were all computed from normal-level ambient noise recordings and, therefore, lobe 18 can be considered relatively stable.

The noise that generates lobe 3 is propagating from a region containing numerous streams and waterfalls. The fluctuating peak at 1.4 cps

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*Texas Instruments Incorporated, 1966: Cumberland Plateau Seismological Observatory Quarterly Rpt No. 3, AF 33(657)-14648, 29 March.

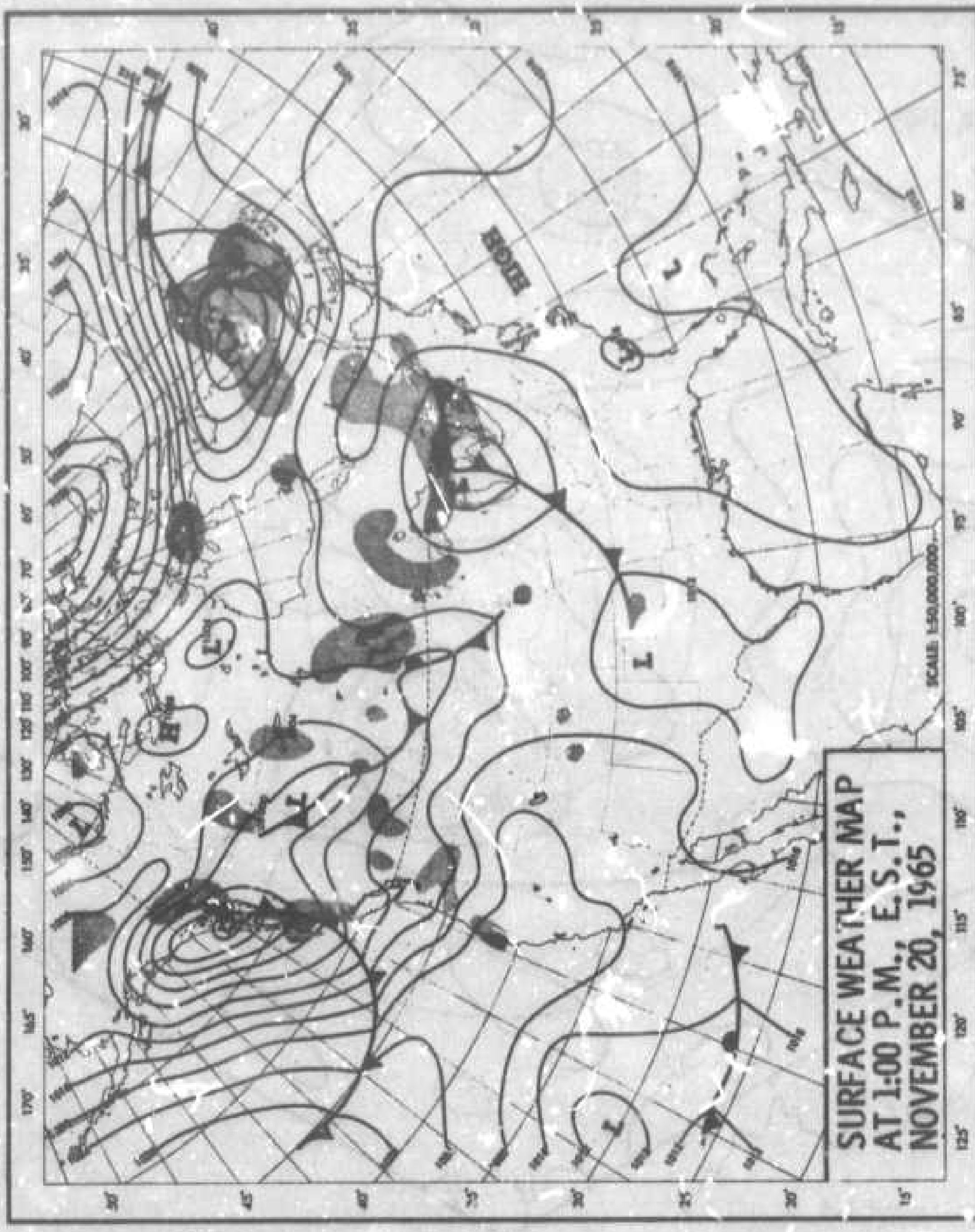

Figure IV-7. Surface Weather Map at 1:00 P.M., E.S.T., 20 November 1965

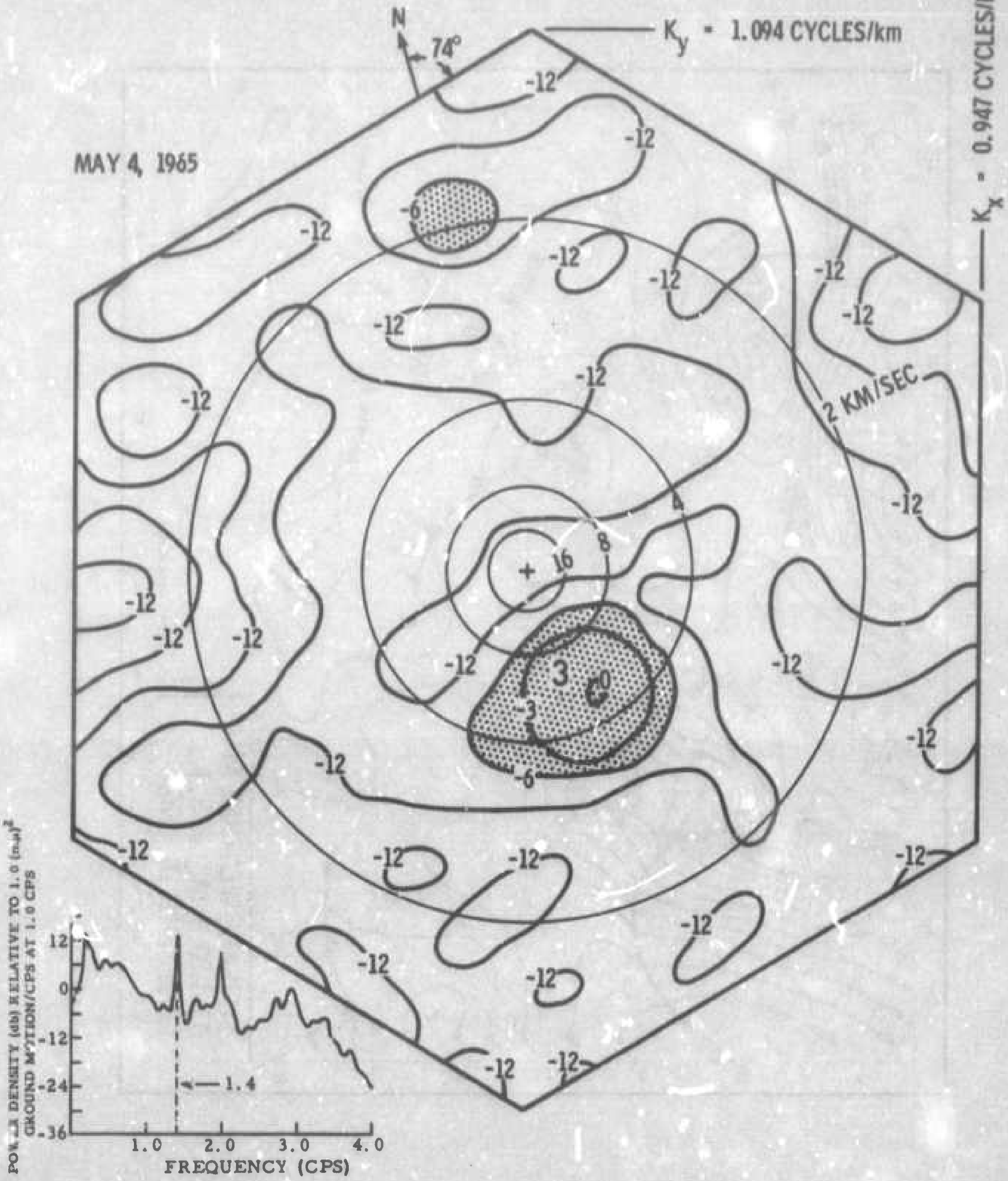

Figure IV-8. CPO Ambient Noise Frequency-Wavenumber Spectrum (f = 1.4 cps) and Power-Density Spectra, 4 May 1965

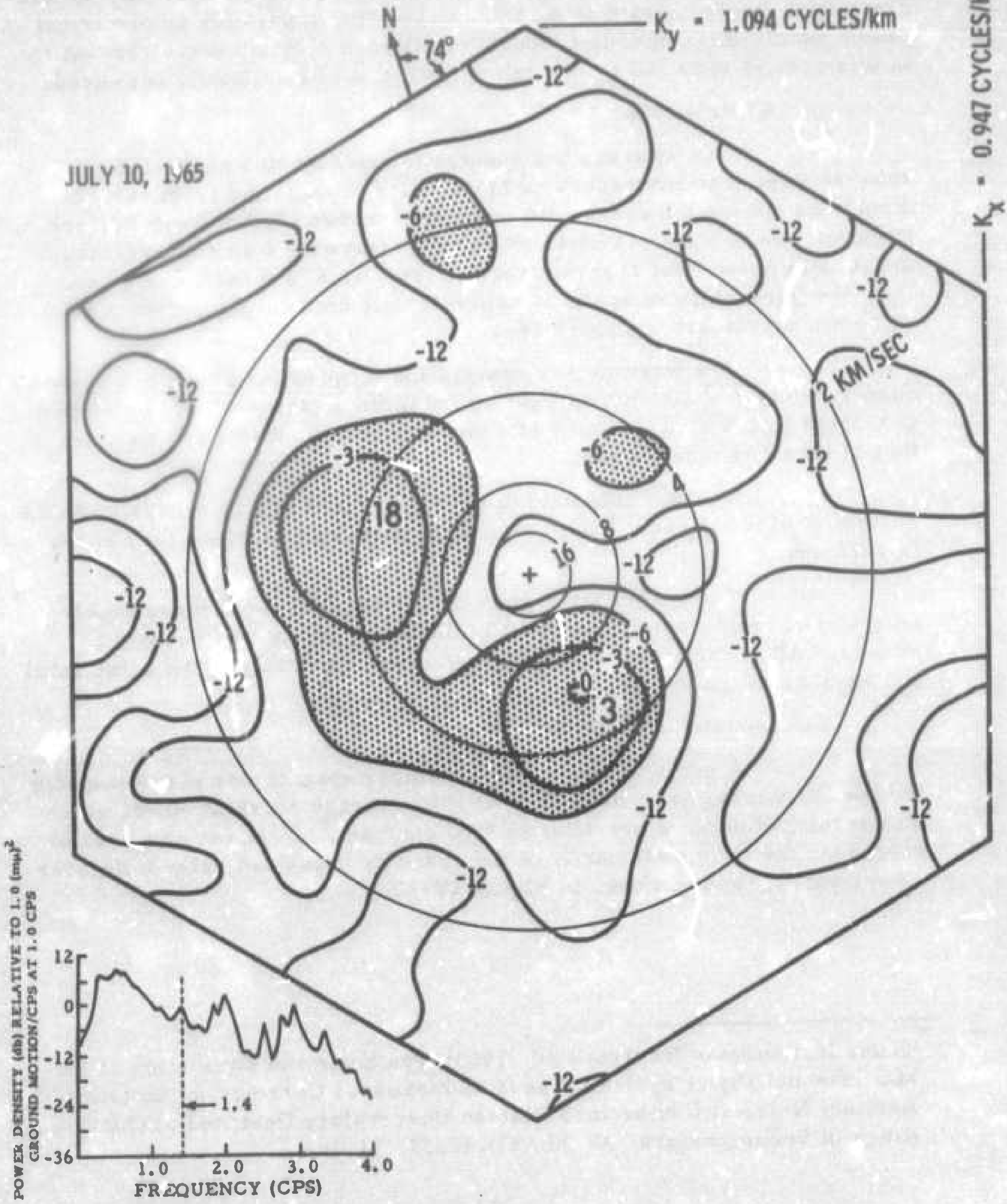

Figure IV-9. CPO Ambient Noise Frequency-Wavenumber Spectrum (f = 1.4 cps) and Power-Density Spectra, 10 July 1965

is believed to be related to some kind of heavy industrial operation in this area which would operate on a random schedule — possibly an electrical power plant. An operating schedule of all such possible noise generation in this area is required before this question can be definitely answered.

c. Other Lobes

The wavenumber spectra for frequencies above 1.5 cps show several spatially organized noise lobes propagating from various directions across the array with velocities between 2.0 and 4.5 km/sec. However, these coherent noise lobes represent only a small percentage of the total noise field at these frequencies. This is most clearly seen from the percentage of spatially unpredictable noise at these frequencies, as shown previously in Figure IV-1.

The wavenumber spectra for frequencies above 1.5 cps show two lobes, 2 and 9, propagating from the northeast. The noise that generates lobe 9 appears to be of a velocity greater than 4 km/sec, while that of lobe 2 is much lower.

The two coherent noise lobes, 4 and 6, are generated to the southwest of the array. The predominant frequency at which they appear is 1.75 cps.

The only other significant coherent noise at these higher frequencies is generated northwest of the array and is represented by lobe 11. All of the above-mentioned lobes are generally of the same level and fluctuate slightly.

2. Comparison of 1963 Data

A set of frequency-wavenumber spectra was also computed for the 10-channel array from a CPO 1963 average correlation set which was developed under a previous AFTAC contract.* This set was used to determine the time stationarity of the spatially organized noise field over a 2-yr period, and is shown in Figure IV-10.

*Texas Instruments Incorporated, 1963: Synthesis and Evaluation of Six Multichannel Filter Systems Based on Measured Correlation Statistics of Ambient Noise at Cumberland Plateau Observatory Designed to Operate on Rings of Seismometers, AF 33(657)-12331, 31 Dec.

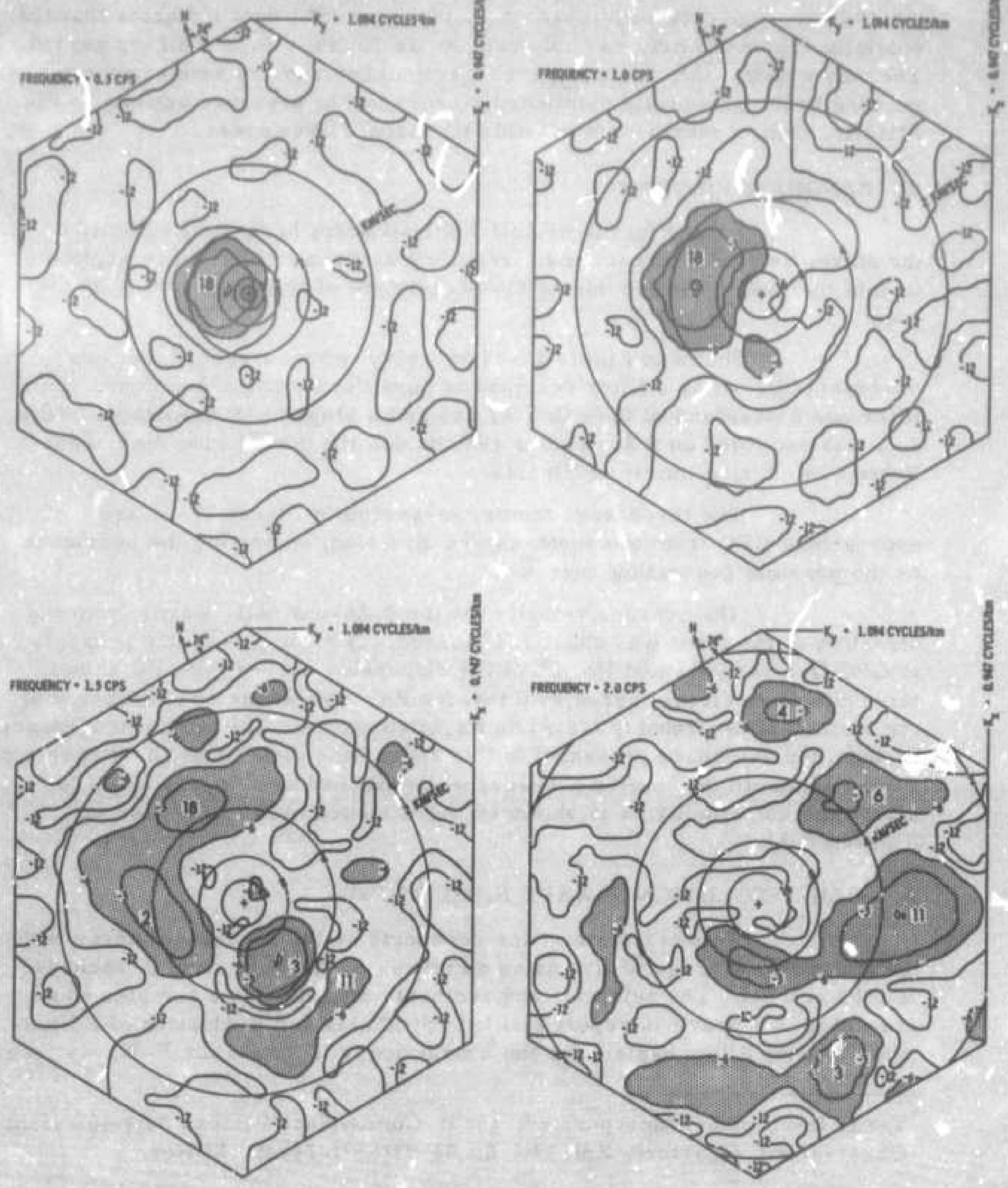

Figure IV-10. CPO Ambient Noise Frequency-Wavenumber Spectrum, 1963 Average Noise Sample

A comparison of the frequency-wavenumber spectra set for the 1963 average data with those computed from 1965 data indicates that the spatially organized field has not changed significantly over the 2-yr period. The only significantly deviating 1965 wavenumber spectra sets are those relating to the previously mentioned storm and low pressure activity in the Atlantic, Gulf of Mexico and possibly the Great Lakes areas.

C. BANDPASS FILTERING

In an effort to establish the apparent horizontal velocity of the storm-related microseisms, frequency bandpass filters were applied to data that was recorded during the occurrence of tropical storms off the coast.

Shown in Figure IV-11 is a playback of a record that has been bandpass-filtered by a filter designed to pass the 4-sec period noise. This filter has a passband of 0.21 to 0.27 cps and a slope of 18 db/octave. This data was recorded on 5 September 1965 during the period when Hurricane Betsy was nearing the tip of Florida.

The three wave fronts, measured in Figure IV-11 are approaching CPO from the southeastern direction, indicating the hurricane as the possible generating source.

The average velocity for the 0.25-cps noise waves from the direction of the coast was about 3.2 km/sec. A study previously presented in CPO Quarterly Report No. 2* of the dispersion curves for CPO shows this velocity to closely agree with that for Rayleigh waves and, hence, that the microseisms probably travel as Rayleigh waves. The slight discrepancy between the velocities presented in this report and those from the dispersion curves is due to the limited accuracy of the method used in this study to determine the velocity as is shown by the variance in the velocities in Figure IV-11.

D. HIGH RESOLUTION P-WAVE NOISE STUDY

This noise study was conducted on the 19-channel array with the statistical average of five noise samples, A, B, E, F, and I, recorded in 1963 at CPO. The selection and synthesis of these noise samples were presented in a previous report entitled "Synthesis and Evaluation of a Nineteen-Channel Filter System for the Extraction of Teleseismic P-Waves from

* Texas Instruments Incorporated, 1965: Cumberland Plateau Seismological Observatory, Quarterly Rpt. No. 2, AF 33(657)-14648, 15 Nov.

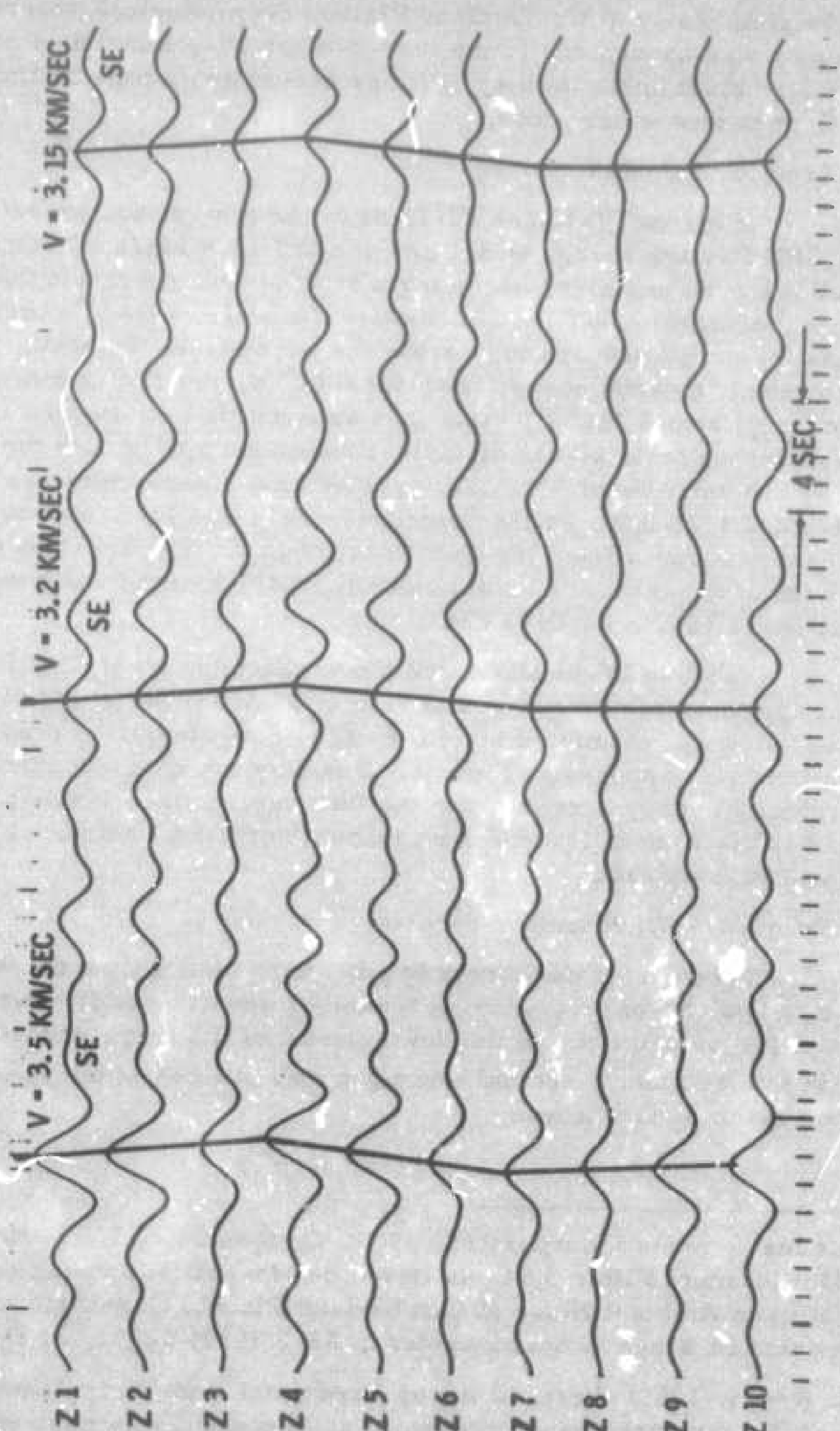

Figure IV-11. CPO Frequency Band-Limited Noise Sample, 5 September 1965

Ambient Seismic Noise at Cumberland Plateau Seismological Observatory.[*] The 1963 data was chosen due to the lack of other 19-channel data and also because the ambient noise field at CPO has proven to be time stationary over the 2-yr period under study.

1. Directional P-Wave Energy

Figures IV-12 and IV-13 show the directional power distribution of CPO P-wave energy at 8.1 km/sec and 12.6 km/sec, respectively. Six directions were examined beginning with 0° at true north and then taking an azimuth increment of 60° in a clockwise direction. The 0° curve represents P-energy propagating across the array from the south, the 60° curve represents P-wave energy from the S 60° W, the 120° curve represents P-wave energy from S 120° W, etc. It is apparent in both figures that the power distribution from all six directions examined approaches the estimated mantle P-wave noise level.[**] Also, predominate contributors are detectable at 1.0 and 1.25 cps. At the velocities of 8.1 and 12.6 km/sec, the 1.0 cps energy arrives from the Gulf Coast region. The 1.25 cps energy arrives with an apparent horizontal velocity of 8.1 km/sec and comes from the Great Lakes region north of CPO.

Figure IV-14 shows the power distribution of CPO P-wave energy at apparent infinite horizontal velocity. Again the power distribution is seen to follow the estimated mantle P-wave noise level. A predominate noise source again appears at 1.0 cps. Possibly the apparent infinite horizontal velocity energy arrives from the Gulf region since it was observed that this was the case at 1.0 cps for apparent horizontal velocities of 8.1 km/sec and 12.6 km/sec.

2. Frequency-Wavenumber Spectra

Since it is necessary to smooth and normalize the data, the normal development of frequency-wavenumber spectra yields power data which is of low resolution. In the development of the frequency wavenumber spectra in this section, a special technique was utilized which yields high resolution spectral estimates.

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* Texas Instruments Incorporated, 1963: Synthesis and Evaluation of Six Multichannel Filter Systems Based on Measured Correlation Statistics of Ambient Noise at Cumberland Plateau Observatory Designed to Operate on Rings of Seismometers, AF 33(657)-12331, 31 Dec.

** R. B. Roden, 1965: Vertical Array Experiments at Uinta Basin Seismological Observatory, paper presented at 35th Annual Meeting of the Society of Exploration Geophysicists, Dallas, Texas, Nov.

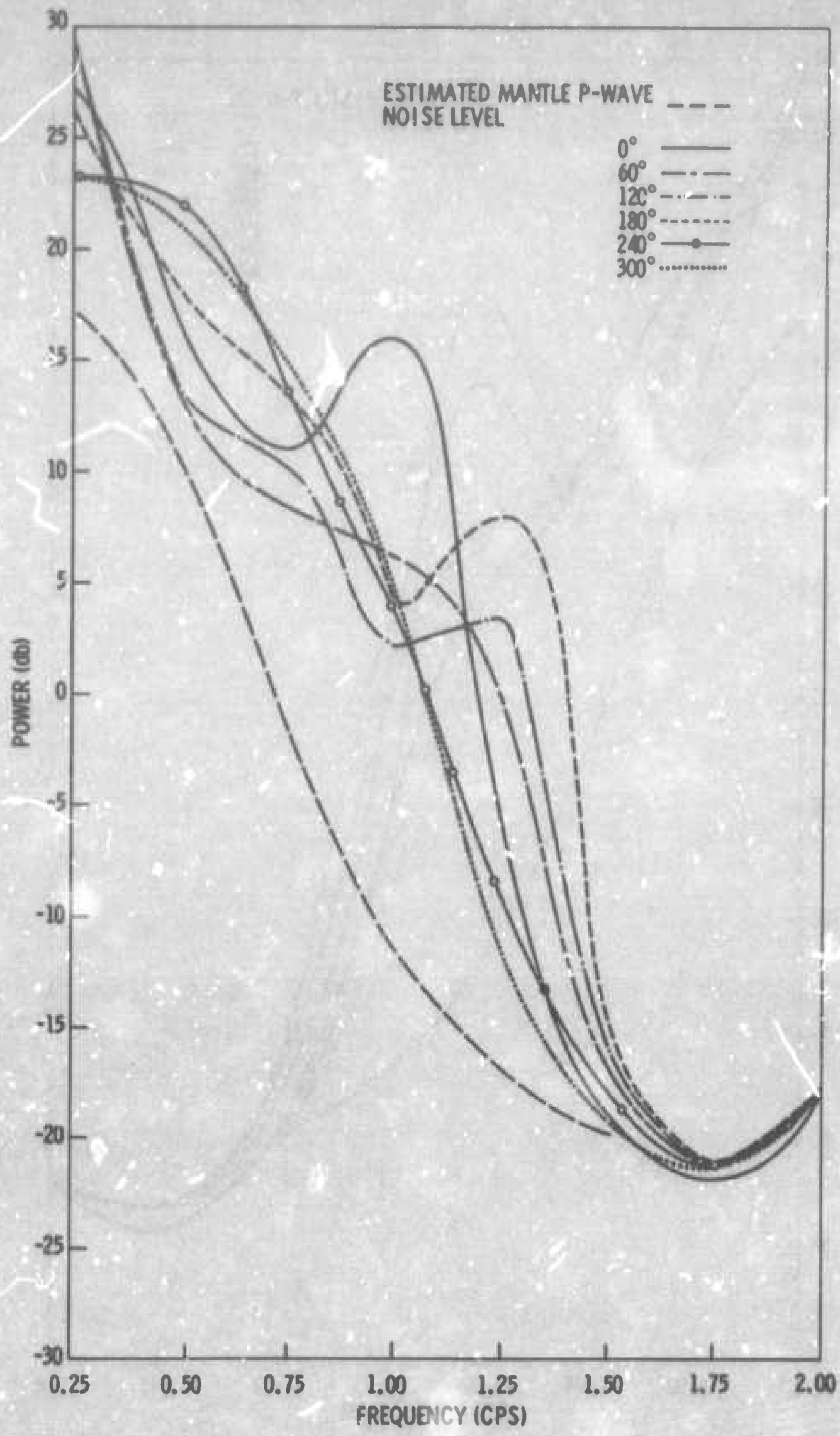

Figure IV-12. Directional Power Distribution of CPO P-Wave Energy at 8.1 km/sec

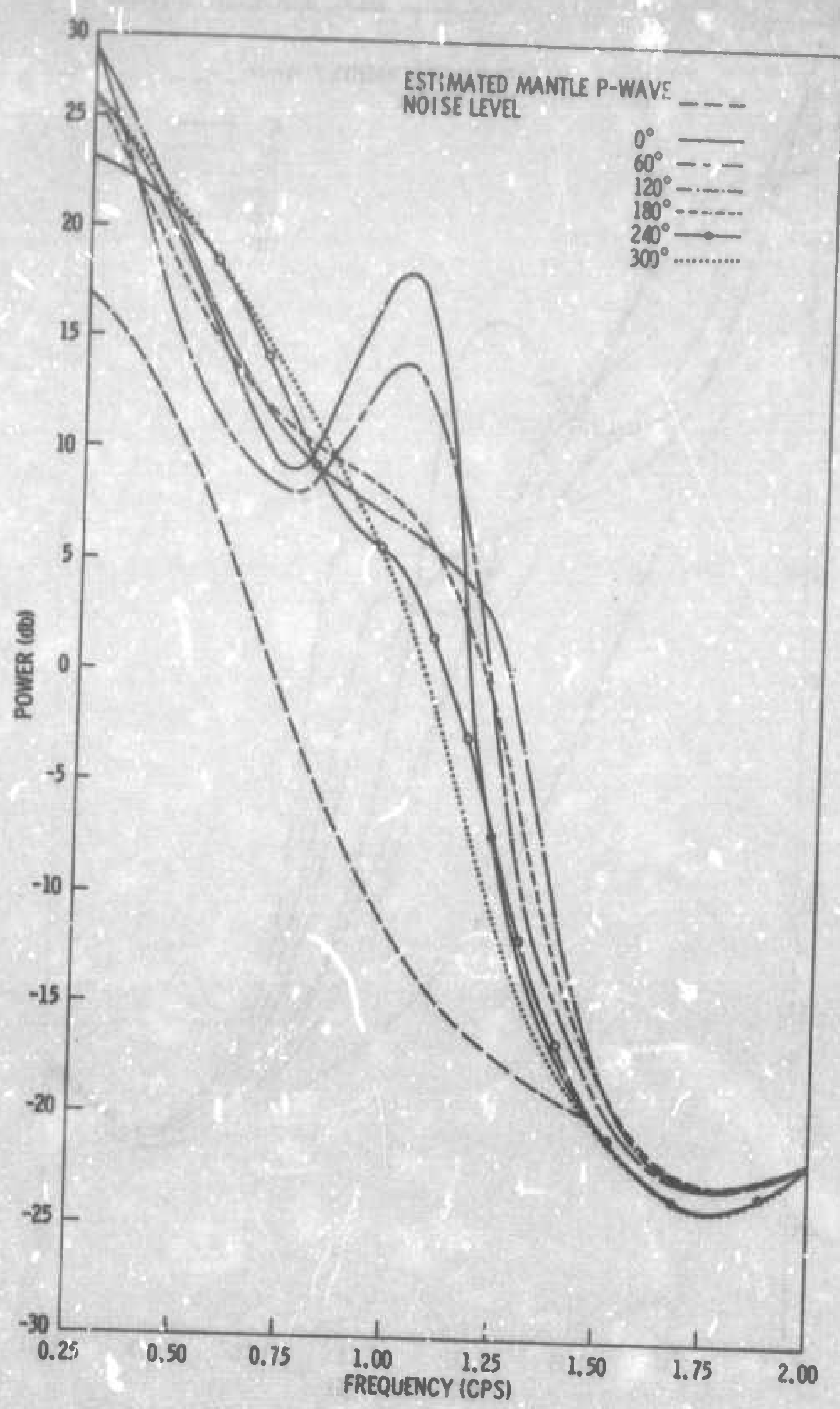

Figure IV-13. Directional Power Distribution of CPO P-Wave Energy at 12.6 km/sec

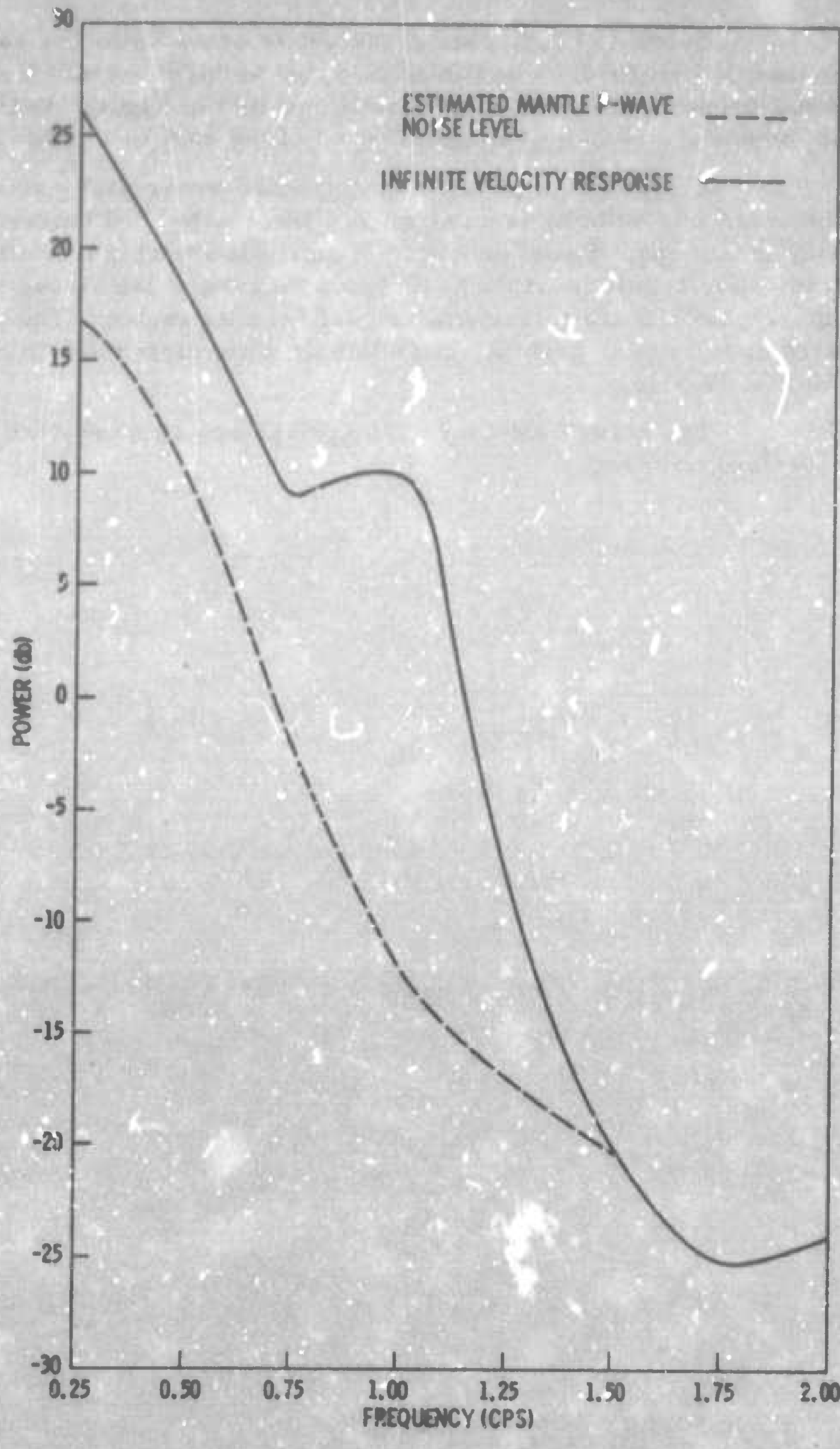

Figure IV-14. Power Distribution of CPO P-Wave Energy at Infinite Velocity

Below 1.0 cps, almost the entire noise field, for velocities greater than 5.0 km/sec, is spatially coherent ambient noise. However, directional properties are detectable as illustrated in Figure IV-15 for 0.5 cps, where the noise power appears out of the east or northeast.

Figure IV-15 shows a strong noise power peak arriving from the south at a velocity from about 7.0 km/sec to 18.0 km/sec at a frequency of 1.0 cps. Signal detection of an event arriving from the south under this noise condition would be difficult because of the strong presence of the noise power in the teleseismic signal velocity region. The predominate noise at 1.0 cps is probably correlatable with microseismic activity in the Gulf of Mexico.

The noise field above 1.5 cps appears to be spatially random to the 10-element array.

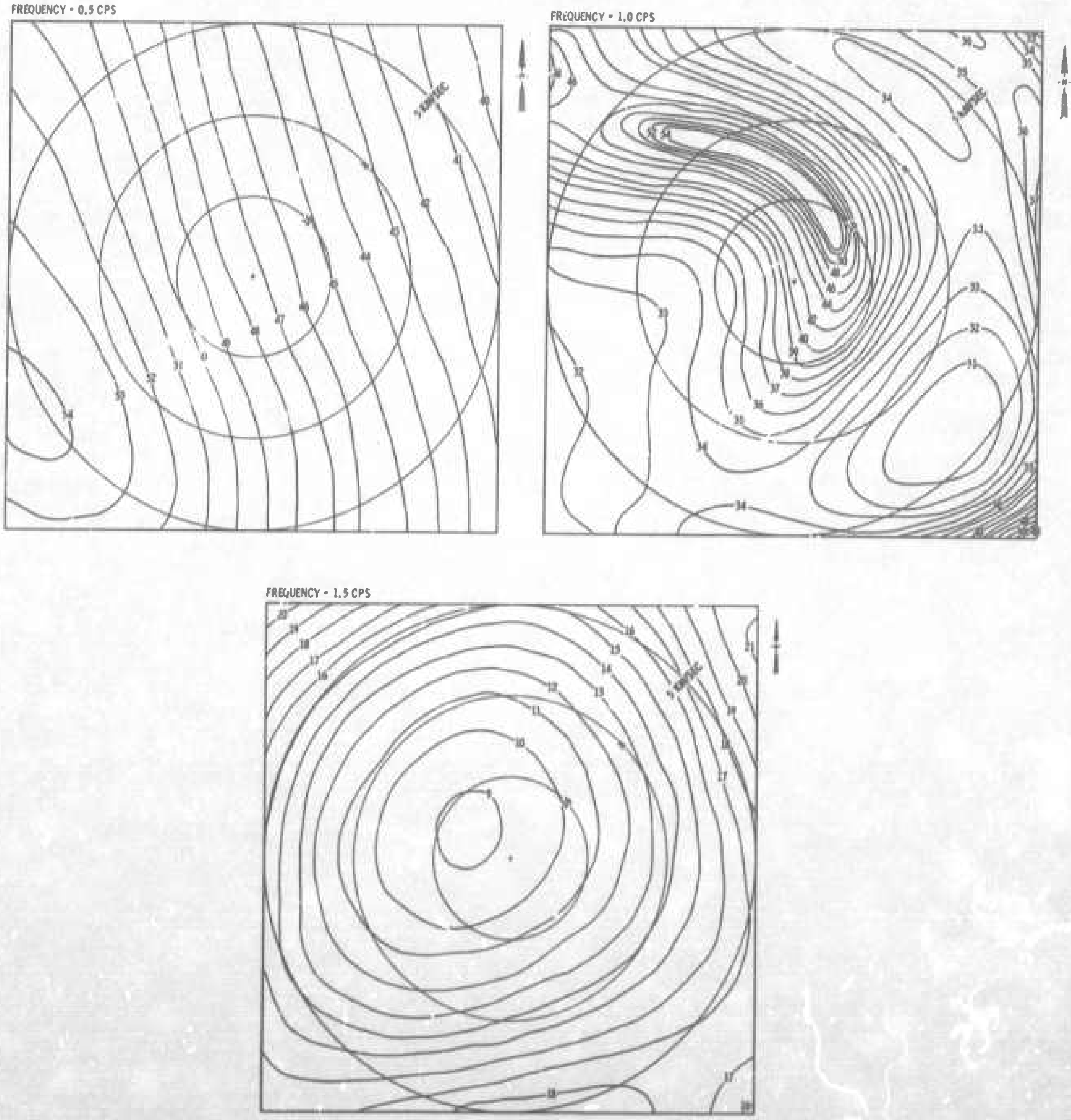

Figure IV-15. CPO High Resolution Frequency-Wavenumber Spectrum, 1963 Average Noise Sample

APPENDIX A

A BRIEF DISCUSSION OF STORM-GENERATED AMBIENT NOISE

APPENDIX A

A BRIEF DISCUSSION OF STORM-GENERATED AMBIENT NOISE*

The subject of storm-generated seismic noise has been of great interest to seismologists for many years. Scientists have long endeavored to understand how storms over large bodies of water generate seismic noise. A brief review of earlier work on seismic noise generation by various scientists is presented in this appendix.

Generally, storm microseisms are restricted to energy of periods from 2 to 10 sec. The energy is believed to travel mainly as Rayleigh waves and, to a lesser degree, as Love waves. Most theories assert that storm-generated noise can travel over long oceanic or continental paths with little attenuation but is greatly attenuated when passing from one medium to the other. The variations in noise energy from one place to another is related to the basic seismic proagation problem which involves geologic structure.

The generation of the storm microseisms was first explained by Wiechert in 1907** His "surf" theory stated that seismic waves are generated by ocean waves breaking along rocky coasts and that they travel long distances with little attenuation. Until about 1930 all observed evidence strongly favored the "surf" theory. However, during the next 20 years observations of increased microseisms which correlated to deep-ocean storms led to the development of other theories to explain the mechanism of generations.

Banerji*** first attempted to explain theoretically the energy transmission from the storm center to the ocean bottom by progressive gravity waves. His theory was based on the compressibility of water, but

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* University of Michigan Institute of Science and Technology, 1964: The history and science of microseisms, VESIAC State-of-the Art Report 4410-64-X, Apr.

** E. Wiechert, 1907: Discussion verb der Zweiten Tagung der Permanenten Kommission and Ersten Generalversammlung der Internat. Seism. Assoc., The Hague, p 61-65.

*** S.K. Banerji, 1930: Microseism associated with disturbed weather in the Indian seas, Phil. Trans. Roy. Loc. London, No. 229, p 287-328.

he was never able to determine how progressive ocean waves, with wavelengths of a few hundred meters, could communicate "in-phase" pressure variations over several kilometers in the sea bed below to generate microseisms with wavelength of several kilometers. In a system of progressive ocean waves, the pressure fluctuation integrates to zero over a few wavelengths. However, in 1950 the Longuet-Higgins' theory* proved that this does not happen when the waves meet each other from oblique directions. For such a case there is a nonlinear interaction between the waves, transmitting in-phase pressure fluctuations to great depths and thus generating seismic waves. Such wave interference can occur in the "eye" of a circular depression, behind a fast moving depression and by reflection of waves from coastal areas.

In 1963 Hasselmann** worked out the theory of general excitation of an elastic layered half-space by a random pressure field, in the form of homogeneous and stationary oscillators, rather than discrete harmonic oscillators. The pressure field may be either the pressure fluctuation in the atmosphere or the nonlinear gravity-wave interaction. He employed the concept that appreciable microseisms are generated only by components of the pressure spectrum having the same phase velocities as free seismic waves. In considering the response of a system consisting of a homogeneous elastic half space to a random pressure field acting on the free surface of the system, he found that even though the applied pressure field is stationary the response was nonstationary owing to resonant excitation of free modes of the elastic system.

As models of excitation for his theory, Hasselmann considered nonlinear interaction of ocean waves of almost the same frequency traveling in opposite directions. He also considered atmospheric turbulance which, by nonlinear interactions, produce pressure fluctuations with phase velocities high enough to generate seismic waves. The Hasselmann theory is in general agreement with the Longuet-Higgins theory.

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* N. S. Longuet-Higgins, 1950: A theory of the origin of microseisms, Phil, Trans. Roy. Loc. London, Sep. A, No. 243, p. 1-35.

** K. Hasselmann, 1963: A statistical analysis of the generation of microseisms, Reviews of Geophysics, Vol. 1, No. 2, p. 177-210.

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13. ABSTRACT
This report summarizes the results of a comprehensive analysis of the ambient seismic noise field existing at CPO under Contract AF 33(657)-14648. Results of this study have shown that the ambient noise field at CPO has not changed significantly over extended time periods, nor has it changed on a daily or seasonal basis. These results imply that an accurate modeling of the CPO noise field can be used to generate a multichannel filter set which can be used in a digital MCF processor to reject ambient noise throughout the year, except for periods of intense microseismic activity.

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